U.S. Coast Guard Oceanographic Report

UNITED STATES COAST GUARD

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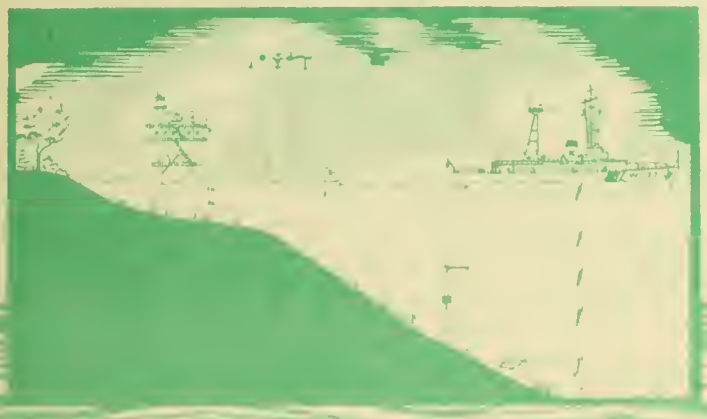
## MEASUREMENTS OF SEA SURFACE TEMPERATURE ON THE EASTERN PACIFIC CONTINENTAL SHELF USING AIRBORNE INFRARED RADIOMETRY

August 1963–July 1968



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UNITED STATES COAST GUARD

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# REPORT No. 47 CG 373-47

## MEASUREMENTS OF SEA SURFACE TEMPERATURE ON THE EASTERN PACIFIC CONTINENTAL SHELF USING AIRBORNE INFRARED RADIOMETRY

August 1963–July 1968

*By James L. Squire, Jr.*

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WASHINGTON, D.C. DECEMBER 1971

Frontispiece. Pacific Coast Continental Shelf sea surface temperature survey aircraft, U.S. Coast Guard HU–16E, Grumman "Albatross".

## Abstract

Airborne surveys were conducted monthly from August 1963 through July 1968, using an infrared radiometer to measure sea surface temperatures and to develop isotherm charts depicting temperature ranges for three areas of the eastern Pacific Continental Shelf. A total of 179 airborne surveys were conducted from aircraft made available by the U.S. Coast Guard as part of their commitment in support of the national oceanographic program. Sea surface temperatures determined by the monthly surveys are presented in contoured charts. Five-year mean sea surface temperatures for each of the three survey areas were determined for each calendar month of the year by 10-minute longitude by 10-minute latitude areas and isotherm charts were drawn from these data.

The mean difference between 146 simultaneously observed airborne radiometer and surface bucket temperatures was −0.35 F° (radiometer lower). The standard deviation was 0.65 F°.

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# Measurements of the Sea Surface Temperature on the Eastern Pacific Continental Shelf Using Airborne Infared Radiometry

James L. Squire, Jr.[1]

## INTRODUCTION

The sea above the eastern Pacific Continental Shelf—a narrow strip of the total marine environment—is a productive area of the Pacific for both plankton and nekton. However, the complex oceanography of the nearshore area is little known, particularly in regard to factors affecting the distribution and migration of its fishery resources. One physical parameter of the ocean environment that is easily measured is sea surface temperature. The relation between sea surface temperature in the eastern Pacific and the distribution and migration of marine and anadromous fishes has long interested fishery biologists. Since this relation provides a possible means of predicting variations in distribution of important marine species, there is an increasing interest in monitoring coastal sea surface temperatures (Hester, 1961; Johnson, 1961; Johnson, Flittner, and Cline, 1965). During years of unusually warm water, southern species have been recorded north of their usual range (Hubbs and Schultz, 1929; Walford, 1931; Radovich, 1961), and variations from the normal pattern of coastal migration have been observed in such species as salmon (Royal and Tully, 1961).

Average sea surface temperature isotherm charts with 2°F contours, based primarily on 1-degree longitude by latitude averages of National Weather Service ship observation data, are issued bimonthly by the National Marine Fisheries Service to provide a partial basis for prediction of albacore (*Thunnus alalunga*) and bluefin tuna (*Thunnus thynnus*) catch distribution (Johnson *et al.*, 1965). A variety of mean and anomaly sea surface temperature charts for the North Pacific, as well as other oceans and seas in the Northern Hemisphere, is computed daily by the U.S. Navy Fleet Numerical Weather Central, Monterey, Calif. (Wolff, 1968). The Canadian Government issues semiweekly sea surface temperature charts (1°F) isotherm contours for the northeastern Pacific. Though these programs obtain data on sea surface temperatures above the eastern Pacific Continental Shelf, the limited number of observations during any one day limits the development of detailed isotherm charts for use within local fishing areas.

One of the problems in determining the relationship of the distribution and movement of pelagic fishes to temperature change has been the lack of an economically feasible means of determining sea surface temperature nearly instantaneously over a large geographical area. The airborne infrared radiation thermometer (ART) provides a rapid means of measurement to fill this need. In August 1963, monthly survey flights of three eastern Pacific Continental Shelf areas (fig. 1) were initiated in cooperation with the U.S. Coast Guard as part of their commitment in support of the national oceanographic program. The three areas selected for survey were important coastal fishing areas and of different physical oceanography—a gyral area off southern California, an upwelling area off central California, and a coastal area off Oregon and Washington, which is under direct influence of a southern segment of the North Pacific Current.

This paper reviews the technique of airborne infrared measurement of sea surface temperature and is a report on the progress of the cooperative program for a 5-year period (August 1963 through July 1968).

## INFRARED RADIOMETRY

Temperature measurements of remote objects are possible because all objects with tempera-

1. National Marine Fisheries Service, Tiburon Marine Laboratory, Tiburon, Calif.

tures above absolute zero (−273.16°C) emit radiation in the infrared range of the electromagnetic spectrum in quantities and at wavelengths that depend on the nature of the radiating object's surface (its emissivity) and on its temperature. The temperature of the earth's surface normally ranges from about −50°C (−58°F) to +50°C (+122°F), with the major portion of the radiation curve lying within the wavelengths of 5 to 20$\mu$ (microns) and the maximum amount of radiant energy between 7 and 13$\mu$. This radiation is attenuated by the gases in the atmosphere, such as water vapor, carbon dioxide, nitrous oxide, ozone, oxygen, methane, and carbon monoxide. However, between the wavelengths of 8 and 13$\mu$ infrared absorption by these gases is much reduced; this band of low absorption of infrared radiation is called an "atmospheric window." Measurement of the earth's radiation reveals that about 30 percent falls within the wavelengths of 8 to 13$\mu$ and can be measured with the use of sensitive detectors and spectral bandpass filters (Frank, 1964).

The sea surface has the characteristic of a good radiant energy absorber and, conversely, a good energy radiator when compared to the characteristics of an ideal, optically black, radiation source. The average emissivity of the sea surface is 0.98 when compared to the ideal blackbody radiation source which is considered to be 1.0. The difference of 0.02 is accounted for in the reflectivity of radiation from the sun and sky from the sea surface. To measure the sea surface radiation, the infrared detector must respond only at those wavelengths at which the atmosphere is nearly transparent (nonabsorbing) and the ocean is nearly black (nonreflecting). This condition is largely fulfilled if the optical system of the radiometer contains filters to pass only the spectral region from 8 to 13$\mu$, for in this region the atmosphere is relatively transparent and the ocean is nearly nonreflecting. The temperature of the sea surface ranges from a minimum of about −2.2°C (28°F), with a radiant energy flux of 0.0304 watts/cm$^2$, to a maximum of +35°C (95°F) with a radiant energy flux of 0.0500 watts/cm$^2$ (Clark and Frank, 1963).

The amount of radiant energy flux at the surface, which is relative to surface temperature, can be measured by an infrared detector and associated electronic components. To accurately determine relatively low temperatures and temperatures having a limited range, such as those of the sea surface, a comparative measurement must be made with a known temperature source. To do this the infrared detector alternately "looks" through the optical filtering system, with the aid of an eight-bladed reflective "chopper" fan revolving in front of the detector, first at the ocean surface and then at a reference blackbody radiation source operating within the instrument at 50°C (122°F). The amplitude of the alternating current wave thus generated represents the temperature difference between the sea surface and the 50°C reference source. The alternating current generated by the detector is amplified, rectified, and sent to a direct current meter and chart recorder. The instrument is calibrated by exposing the optical detector to an external heat source which can be varied to cover the required range of observed temperatures.

Airborne infrared radiometry has been used occasionally as a technique for determining sea surface temperature gradients for over a decade. In the early 1950's experiments were conducted on determination of infrared radiation from the sea surface by the Woods Hole Oceanographic Institution under contract with the U.S. Navy, Bureau of Aeronautics. The instrument used was designed to determine the horizontal gradients of sea surface radiation rather than to measure the radiation in terms of degrees F. or C. In 1952 the airborne infrared technique was used to determine surface radiative gradients and map the location of the Gulf Stream front (von Arx, Bumpus, and Richardson, 1955). Ewing (1952) modified the instrument and used this technique to measure infrared radiation gradients in the eastern tropical Pacific. He reported that the radiation thermometer "appeared to be a most useful oceanographic tool and holds the promise of making it possible to obtain rapid, nearly synoptic, surveys of ocean surface temperatures." He later concluded (Ewing, 1964) that horizontal temperature gradients are much more precisely defined by the ART than is absolute temperature. He also concluded that thermal maps should be of use to marine biologists and physical oceanographers in defining areas having convergence which may in turn have an effect

on the distribution of fish populations. As a direct application of this technique to fisheries, the Commonwealth of Australia began experiments with an ART in 1964 and since 1966 has produced sea surface temperature charts for the southern bluefin tuna (*Thunnus thynnus maccoyii*) fishing fleet off New South Wales (Hynd, 1968). The Australian ART survey charts indicated the flight path, surface isotherms (°C), fish sightings, and locations of temperature fronts. Areas having favorable conditions for bluefin tuna were noted and reported to the fishing fleet, and subsequently catches were made in these areas.

The temperature of the surface layer of the ocean and the water mass below is affected mainly by radiation absorbed from sun and sky, radiation from the sea into space, evaporation from the sea surface, and conductive exchanges between sea and atmosphere. The shallow surface layers tend to become mixed through wind action and convection, and in certain nearshore areas there is considerable mixing resulting from tidal action. The effect of subsurface phenomena on the surface layers as observed with infrared equipment has been studied by McAllister and McLeish (1965). They described variations in small scale horizontal sea surface temperature structures associated with such physically observed phenomena as fronts, eddies, and surface slicks. Tully (1961) described in detail some of the reasons for sea surface temperature fluctuations, as reflected in the ART record, and the possible relation of these fluctuations to transient thermoclines.

The oceanographic measurement of sea surface temperature has been described by Sverdrup, Johnson, and Fleming (1942) as a temperature measurement taken of a sample of water from within 1 meter of the surface. The ART measures the temperature of the microsurface of the sea and consequently the readings taken from the ART equipment may vary from readings taken by a conventional bucket thermometer. Comparative temperatures determined by a bucket thermometer or near-surface thermistor and the ART indicate differences on the order of ±0.2 C° (Peloquin, Wilkerson, and Hanssen, 1964), ±1.0 C° (Tully, 1964), ±1.0 C° (Clark and Stone, 1964), ±1.0 F° (Squire, 1964), ±0.5 C° (Reintjes, 1964). Pickett (1966) found ART readouts to be 0.3 to 1.8 C° lower. Hynd (1968) in his work off Australia reports comparative observations which indicated a mean difference of ±0.5 C°.

## METHODS AND EQUIPMENT

In October 1962, the Tiburon Marine Laboratory began experiments with an ART, testing its reaction to atmospheric attenuation of the incoming infrared signal due to the effects of altitude and moisture (haze) and measuring the instrument's repeatability over ranges of sea surface temperature. Continuous surveys of near-shore surface temperatures were made from the Mexican border to Cape Flattery, Wash. Surveys were also made of north San Francisco Bay, Sacramento River, Santa Barbara Channel, and of several warm sea water discharges from coastal steam-electric generating plants (Squire, 1967). Operational experience gained in the conduct of these surveys made it possible to initiate a coastal survey program in cooperation with the U.S. Coast Guard.

Infrared equipment used in coastal surveys was manufactured by the Barnes Engineering Co., Stamford, Conn. Models 14–312, IT–1, and IT–2 were used. Temperature information from these units was continuously recorded by a Model G–14 analog strip chart recorder manufactured by Varian Associates, Palo Alto, Calif. The problems of mounting and operating infrared equipment of laboratory grade in an environment of high noise and vibration of an aircraft have been discussed by Barnes (1964), Squire (1964), Peloquin, *et al.* (1964), and Clark and Stone (1964). Stability of the aircraft power supply, physical and sonic vibration resulting from propeller or engine noise, and air turbulence were the principal problems encountered in airborne operations.

Each ART unit (ART electronics, recorder, power supply, and metering equipment) was mounted on a wooden panel (fig. 2), which was secured in the aircraft by mounting the panel across the armrests of a standard aircraft double seat. The power supply unit consisted of an inverter (28 Vdc to 115 Vac, 60 Hz), a frequency meter, a switch panel with two voltmeters (18–36 Vdc, 0–150 Vac), and a polarity selector switch for the direct current voltmeter.

The inverter was powered by the aircraft 28 Vdc system, and a rheostat was provided to control the inverter input voltage. The ART electronic circuitry was modified by adding capacitance to the output circuit to reduce excessive fluctuations in the temperature record. An opening was made in the instrument case to provide access to the electronic circuitry for the purpose of making in-flight calibration adjustments. In addition to the fixed electronic equipment, accessory items including an insulated water container and standard mercury thermometer were carried for use in calibration of the ART.

The ART detector head was adjusted to view the sea surface through the open lower half of the port double-door hatch, at an angle of approximately 15° to 20° from the vertical. This angle was within angular viewing limits of the instrument for accurate sea surface temperature measurements (Frank, 1964) and allowed positioning of the detector head within the aircraft where air tubulence was minimal, yet where the detector had an unobstructed view of the ocean surface. The detector head was mounted on a rubber shockmount attached to a screw clamp and bracket. The screw clamp was fastened to a vertical handhold and the detector head was partially suspended by rubber tubing to provide a fully shock-dampened mounting. A plywood panel was fitted into the lower half of the port hatch, filling approximately three-quarters of the opening, to reduce the amount of air turbulence within the aircraft cabin.

## OPERATIONAL PROCEDURES

U.S. Coast Guard Air Stations at San Diego and San Francisco, Calif., and Port Angeles, Wash., made available Grumman HU–16E "Albatross" twin-engined amphibious aircraft (frontispiece) for each monthly flight. A total of 179 flights was made involving over 1,100 hours flight time, serving the dual purpose of providing an aircraft for oceanographic studies and for low-altitude training for Coast Guard pilots and crew. A 152-meter (500-ft) cruising altitude was selected as a compromise between low elevation to reduce the effect of haze on the ART reading and minumum altitude for safety in case of an engine failure.

Survey flight tracks extended to about 45 nautical miles offshore in the northern and central areas and about 85 miles offshore in the southern area (figs. 3–5). The flight track lines in the northern and central survey areas were not changed during the 5-year period. On numerous occasions survey aircraft in the southern area were not allowed to enter or were diverted out of the area south of the Santa Barbara Channel Islands and south of Point Arguello. These areas were military missile firing areas under the jurisdiction of the U.S. Navy, Pacific Missile Range, and military operations in these areas were at times hazardous to aircraft. In January 1968, the flight track was adjusted to eliminate entry into these firing areas by extending it farther offshore to Cortez Bank, farther offshore from 60-mile Bank, and farther south to near Todos Santos Island, Mexico, (dashed lines on fig. 3).

Prior to the start of a survey flight, power checks were made on the output of the aircraft electrical system and output of the ART inverter power supply. The ART electronic console unit was placed on line and the detector was allowed to reach operating temperature. After takeoff the detector head was adjusted to view the water, the recorder placed in operation, and survey flight track started. The optical field of view of the infrared detector used was 3°. The normal groundspeed of the ART viewing system was 250 km/hr (135 kts., 69.4 m/sec.) Temperature data from all surveys were recorded on a strip chart recorder at a chart speed of 1 inch per minute. Information marked on the strip chart included start times, beginning and ending of legs, geographical points, and any other data that would be useful in correlating the recorder chart with the flight track.

### ART Calibration

In the laboratory, the ART unit was calibrated by scribing a readout grid for the analog recorder while the unit was exposed to a temperature-controlled water bath. The water bath was well mixed by a magnetic stirrer and during the calibration procedure was stabilized at each 1 F° interval (0.66 C°) as determined by a standardized mercury thermometer. The readout grid was made for the temperature range normally expected to be encountered during the survey flights.

In-flight calibration checks were made at intervals during the survey, comparing the ART

readout meter with a well-stirred water bath of a known temperature near that of the ocean's surface. This test determined a correction factor which was the difference between the ART meter readout and the true mercury temperature of the water bath (fig. 6). The temperature correction factor usually remained constant, but was checked at intervals of about 1 hour. If the difference in readings varied, a malfunction in operation was indicated and corrected. This check verified the correct operation of the infrared detector and measurement section of the ART survey unit. The strip chart recorder was checked for uniform operation by noting the ART temperature meter reading in relation to the position of the recorder pen. The ART meter readings were marked on the recorder chart, and any shift in the positioning of the recorder pen relative to similar ART meter readings indicated a malfunction. These two in-flight checks were necessary to insure standardization of performance from the ART unit.

Figure 6 also illustrates the difference between the profile of traces from the ocean surface and from a well-mixed water bath. The fine structure in the ocean trace represents the effect of fluctuation in sea surface temperature as the instrument moves over the ocean's surface. The fine structure in the bath trace indicates the effect of the aircraft's electrical, physical, and sonic interference. In a laboratory environment, the viewing of a temperature-stabilized water bath produces a trace free of fine structure.

During the flights, calibration temperatures were obtained from sea surface measurements made while the plane was overhead. In the northern area simultaneous, comparative temperature observations of the ART and surface bucket cast were made with the UMATILLA (ULV) and COLUMBIA (CRLV) lightvessels; in the central area they were obtained with the SAN FRANCISCO (SFLV) lightvessel. All vessels used surface cast thermometers furnished by the National Weather Service. In the southern area simultaneous observations were made with the NURDC (Naval Undersea Research and Development Center) Oceanographic Tower off San Diego, Calif. A thermistor was used on the tower to determine surface temperature. Comparisons with 146 simultaneous sea surface temperatures showed an average difference of 0.35 F° (ART lower), a range of −1.9 F° to +1.2 F°, and a standard deviation of 0.65 F°.

### ART Coastal Charts—Readout and Plotting

In processing the ART data, the strip chart recorder track was read out, using a calibrated grid adjusted to sea surface temperature observed during the simultaneous airborne-surface check with one of the lightships or the NURDC tower. From August 1963 to January 1966 the recorder track was read out at 30-second intervals, and four observations were averaged to give a 2-minute average temperature. To reduce the amount of time involved in making readouts and averaging calculations, a slide rule-type averaging device was constructed (fig. 7) and used after January 1966. Comparison of the two averaging techniques yielded differences of less than 0.1 F°.

Upon return to the U.S. Coast Guard air station the temperatures were coded onto an Airborne Radiation Thermometer Sea Temperature (ARTST) (U.S. Navy) message form and transmitted via tape or teletype to U.S. Navy Fleet Numerical Weather Central, Monterey, Calif. Later, at the Tiburon Marine Laboratory, 2-minute averages were plotted on the aircraft flight track, and contoured charts were drawn from these data. These isotherm charts were issued without charge by the laboratory to interested persons and biological, oceanographic, and meteorological laboratories.

## RESULTS

### Monthly Isotherm Charts

Temperature data in the form of contoured charts, are located in appendix A for each monthly ART survey in the three survey areas. The temperatures shown on the charts are corrected to agree with sea surface temperature measurements obtained from lightships or the (USNURDC) oceanographic tower during the flights.

### Mean Monthly Isotherm Charts

Temperature data for the 5-year mean monthly isotherm charts (figs. 8–43) were calculated from each monthly survey by determining the average temperature for each 10-minute (longitude by latitude) area. The mean

monthly isotherm charts were drawn from these average data, assuming the average temperature to be located at the midpoint of each 10-minute square.


## ACKNOWLEDGEMENT

The interest and full cooperation of the U.S. Coast Guard made the surveys possible. In particular, the cooperation of the commanding officers, flight operations staffs, and flight crews of the Coast Guard air stations at San Diego, San Francisco, and Port Angeles made a major contribution to the success of the program.

Measurements of sea surface temperature were made (while the ART aircraft was overhead) from the U.S. Coast Guard Lightships SAN FRANCISCO, COLUMBIA RIVER, and UMATILLA, and the NURDC Oceanographic Tower, under the supervision of Dr. E. C. LaFond.

Financial support given the ART program in 1967 and 1968 by the U.S. Navy Fleet Numerical Weather Central, Monterey, Calif., enabled the program to continue without interruption.

Helpful suggestions on the method of analysis of monthly isotherm charts were given by Dr. Sidney R. Frank, consulting meteorologist, Santa Barbara, Calif.


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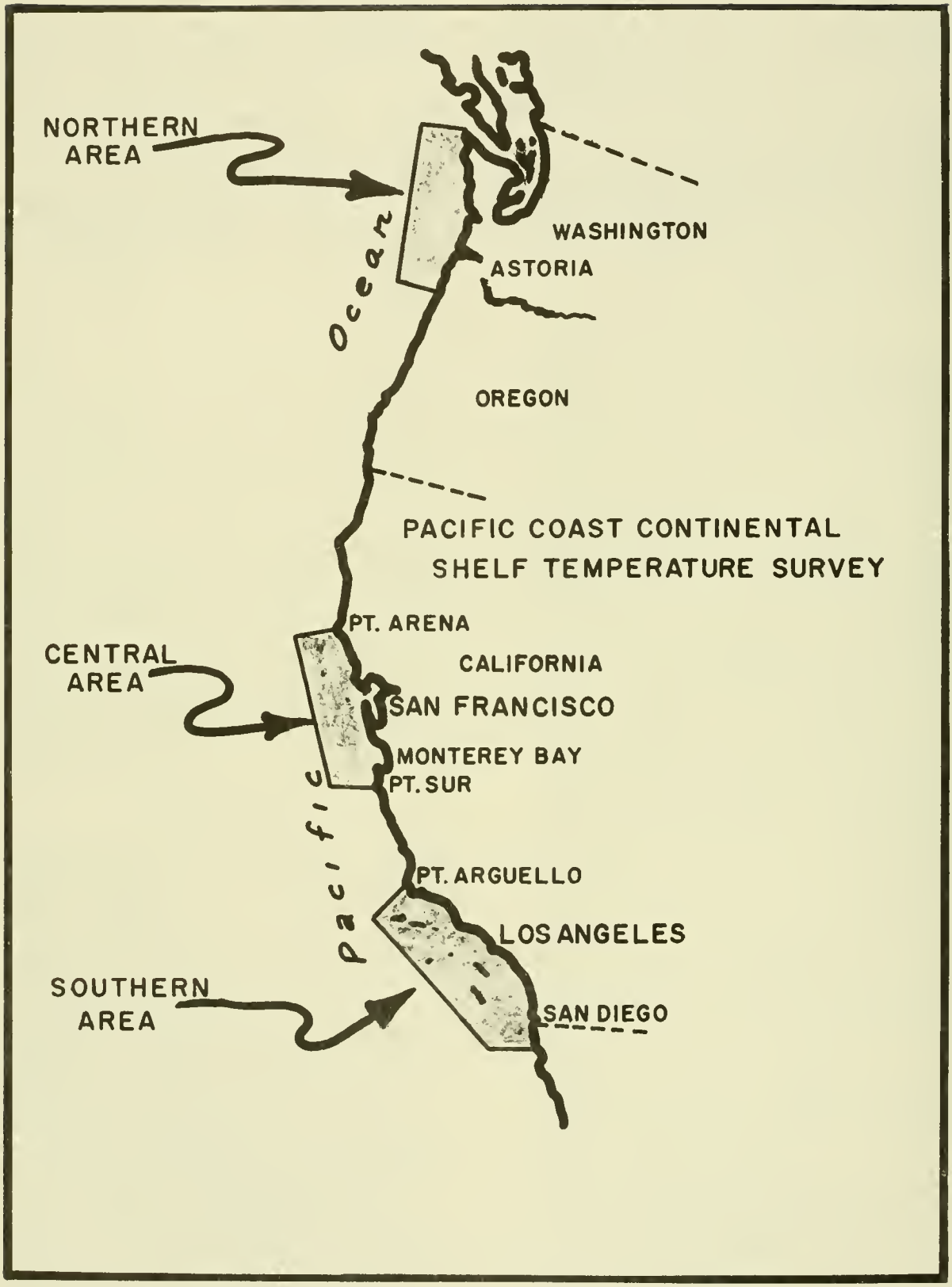



Figure 1. Areas surveyed monthly by the Tiburion Marine Laboratory in cooperation with the U.S. Coast Guard.

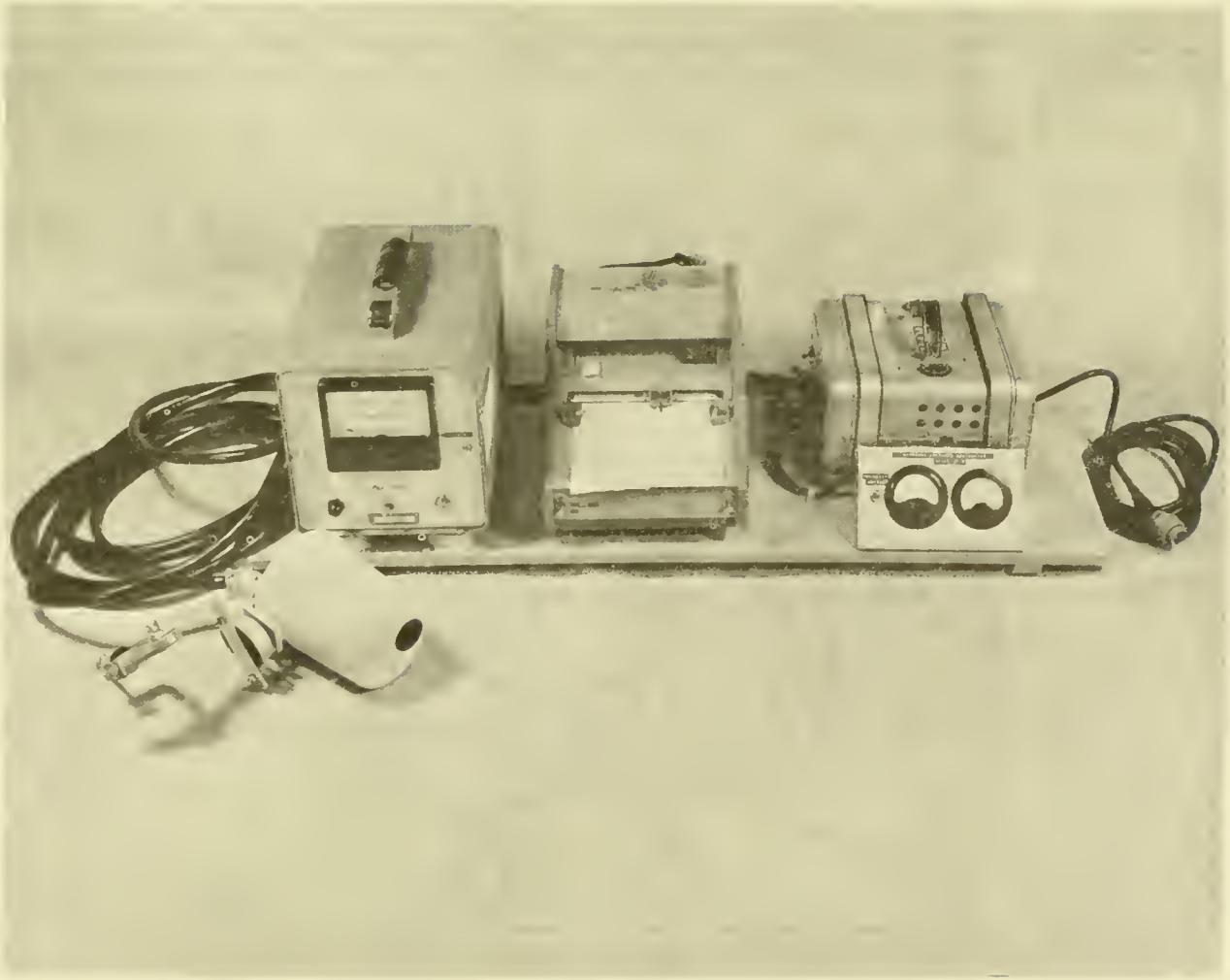


Figure 2. Airborne radiation thermometer unit mounted for use aboard U.S. Coast Guard aircraft.

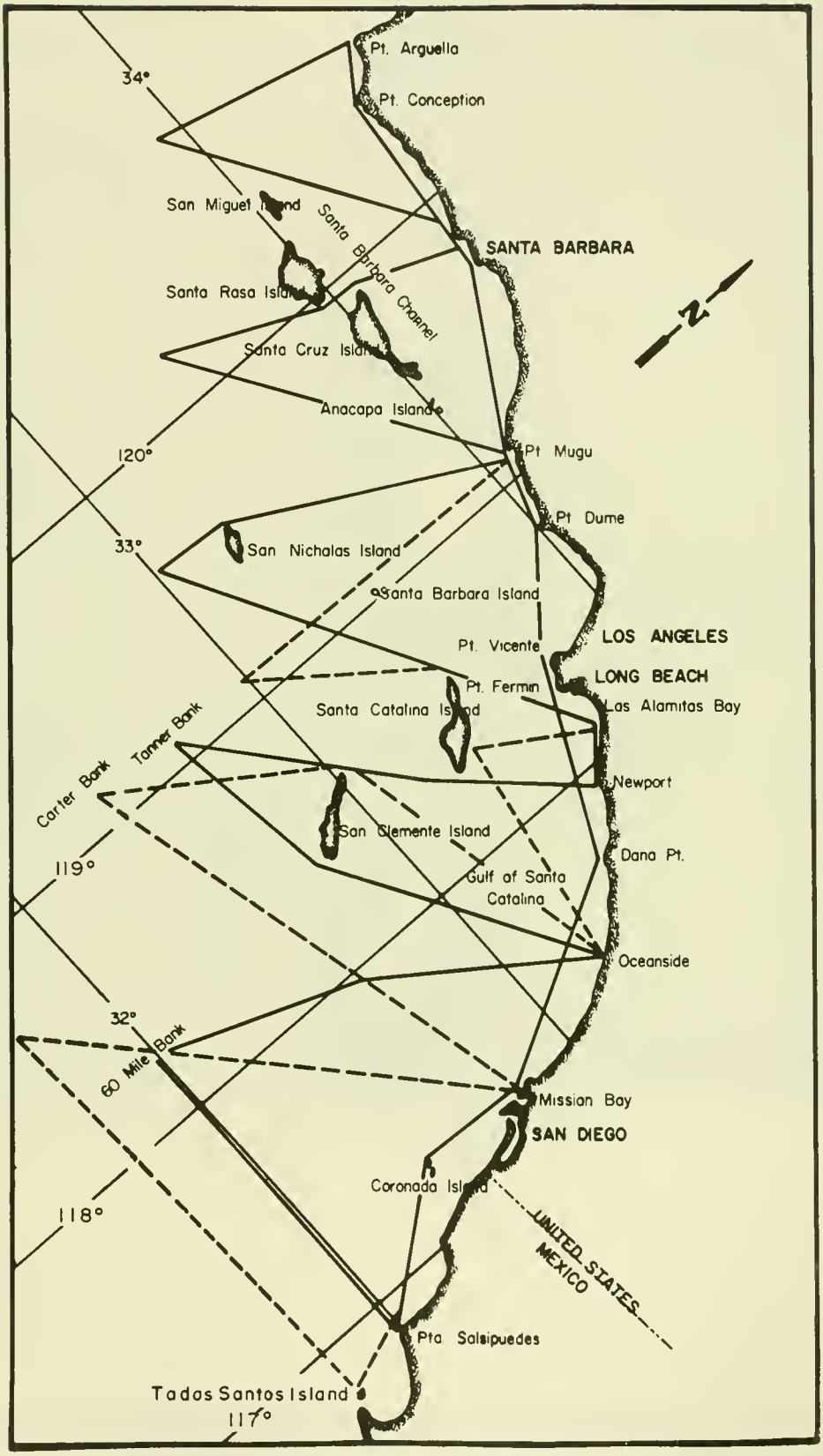



**Figure 3. Southern survey area flight track.**

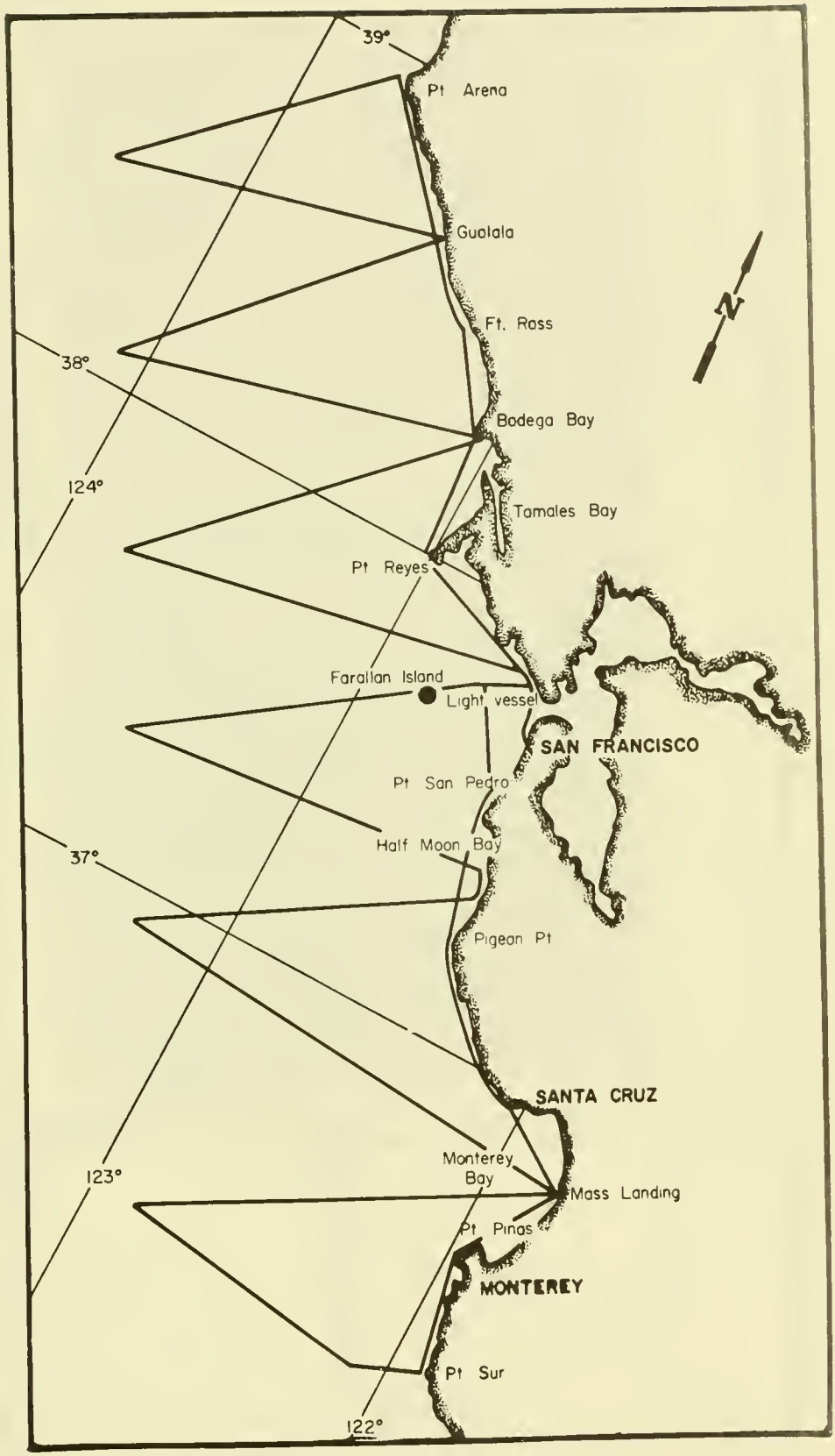



**Figure 4. Central survey area flight track.**

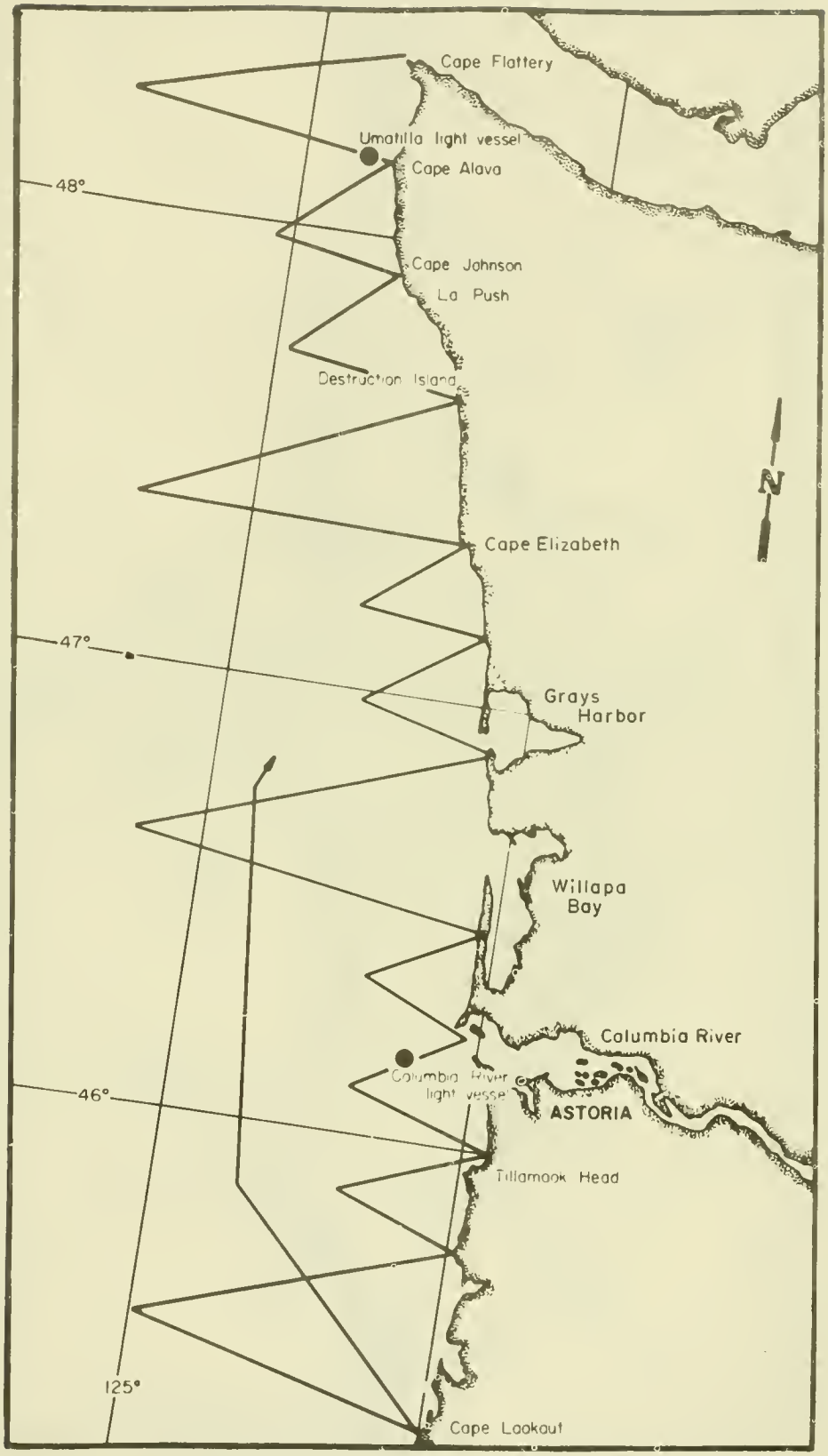



Figure 5. Northern survey area flight track.

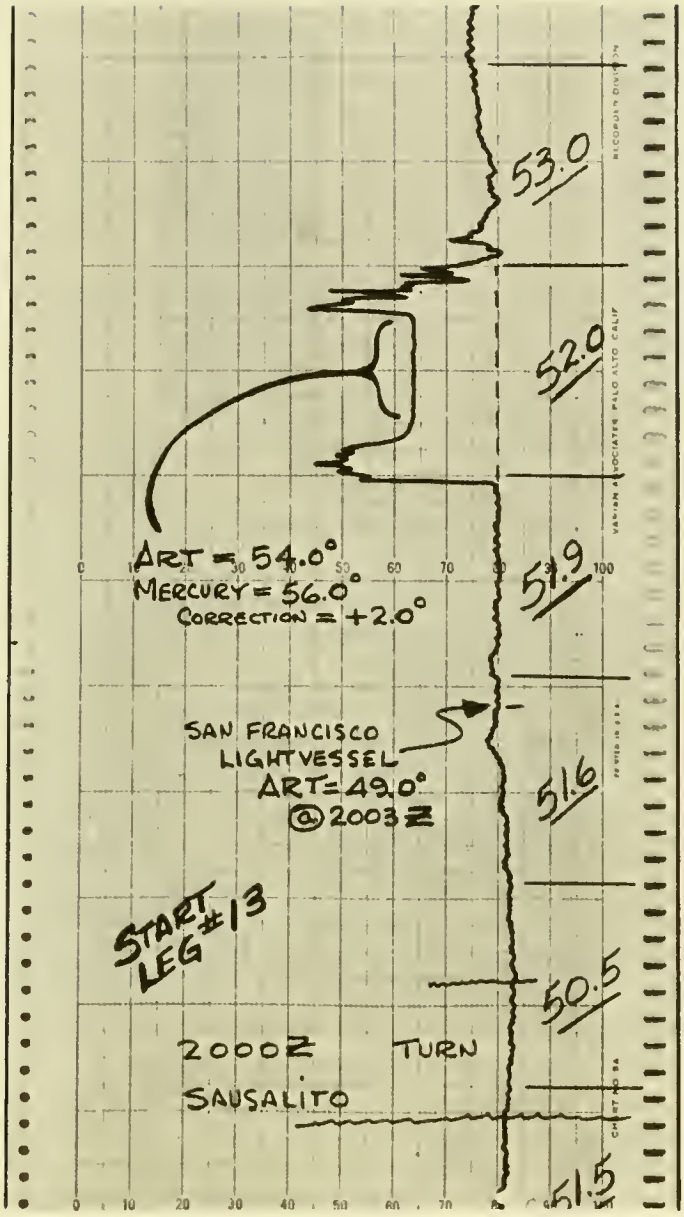



Figure 6. Recorder trace showing the comparative check on the operation of the ART unit made by viewing a well-stirred water bath (shown by the bracket).

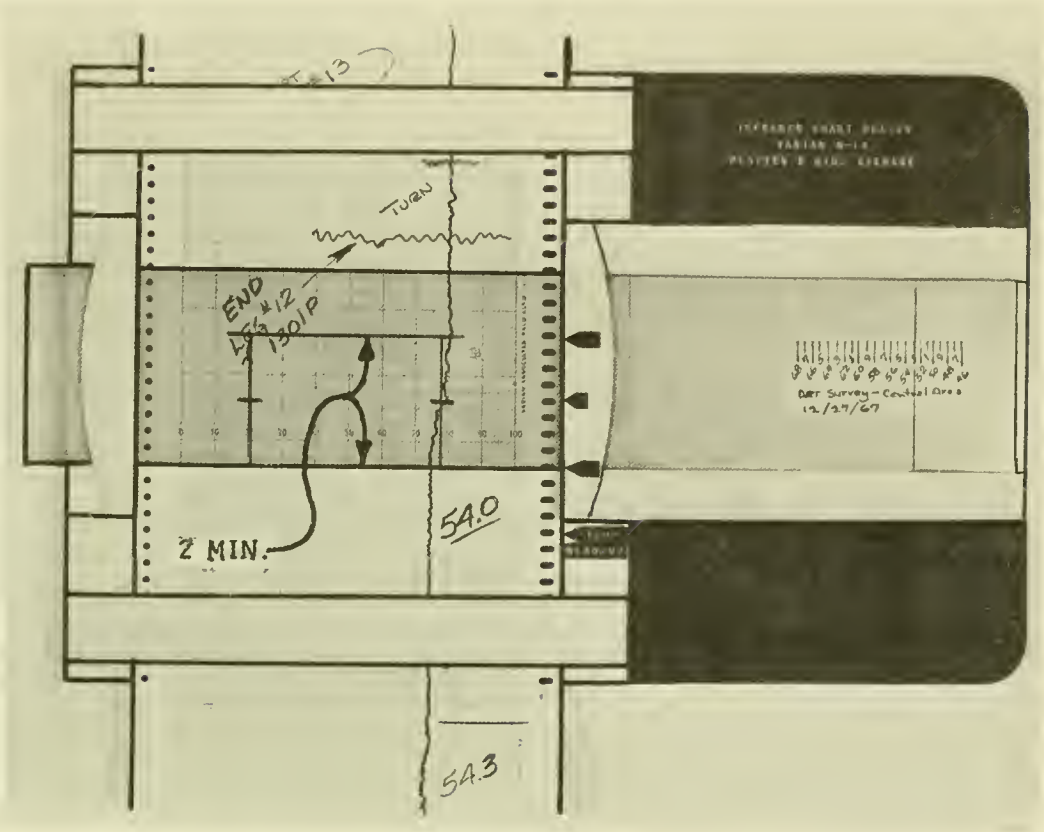



Figure 7. Slide-rule readout device for determining 2-minute average temperatures.

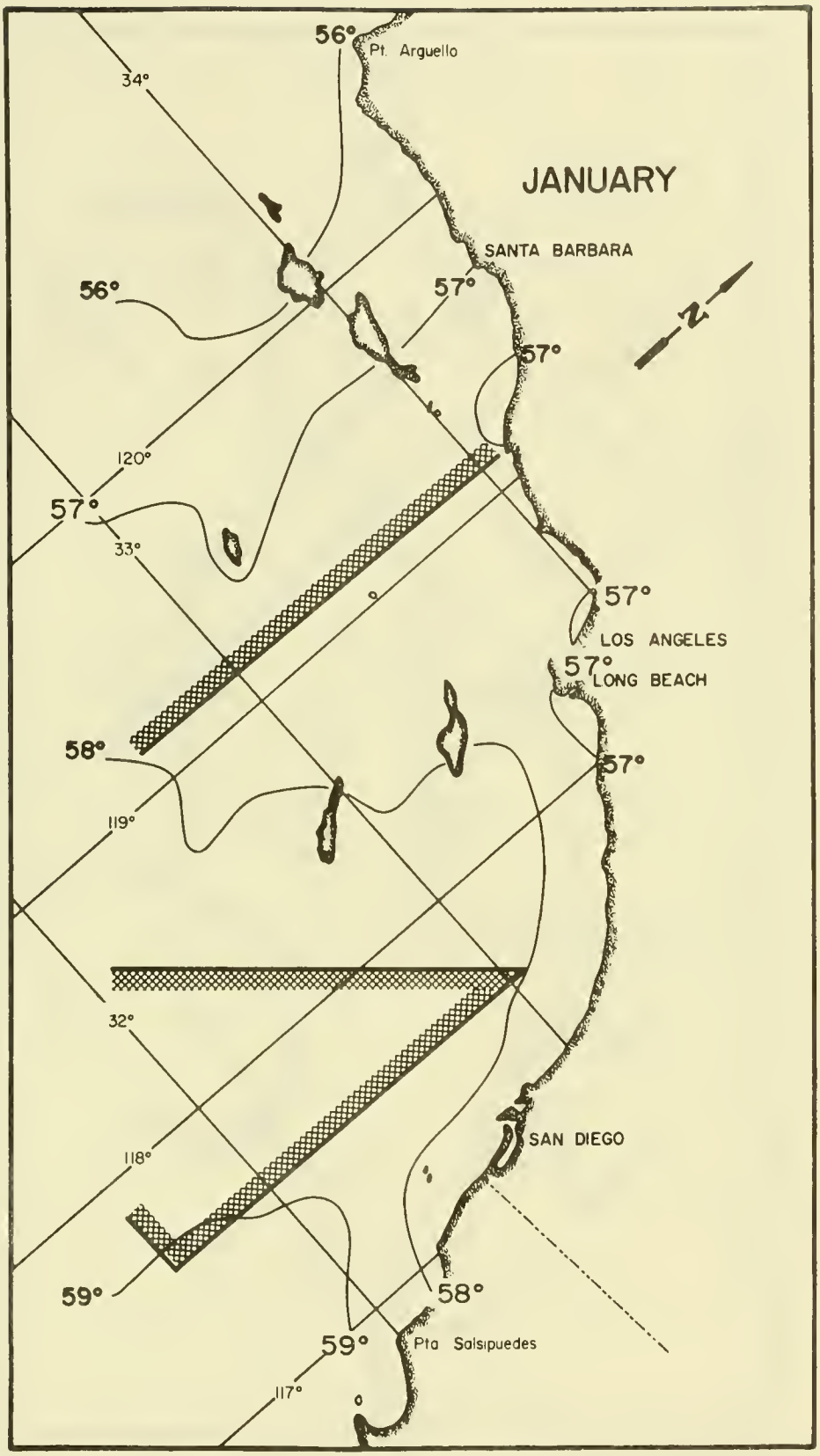



**Figure 8. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.**

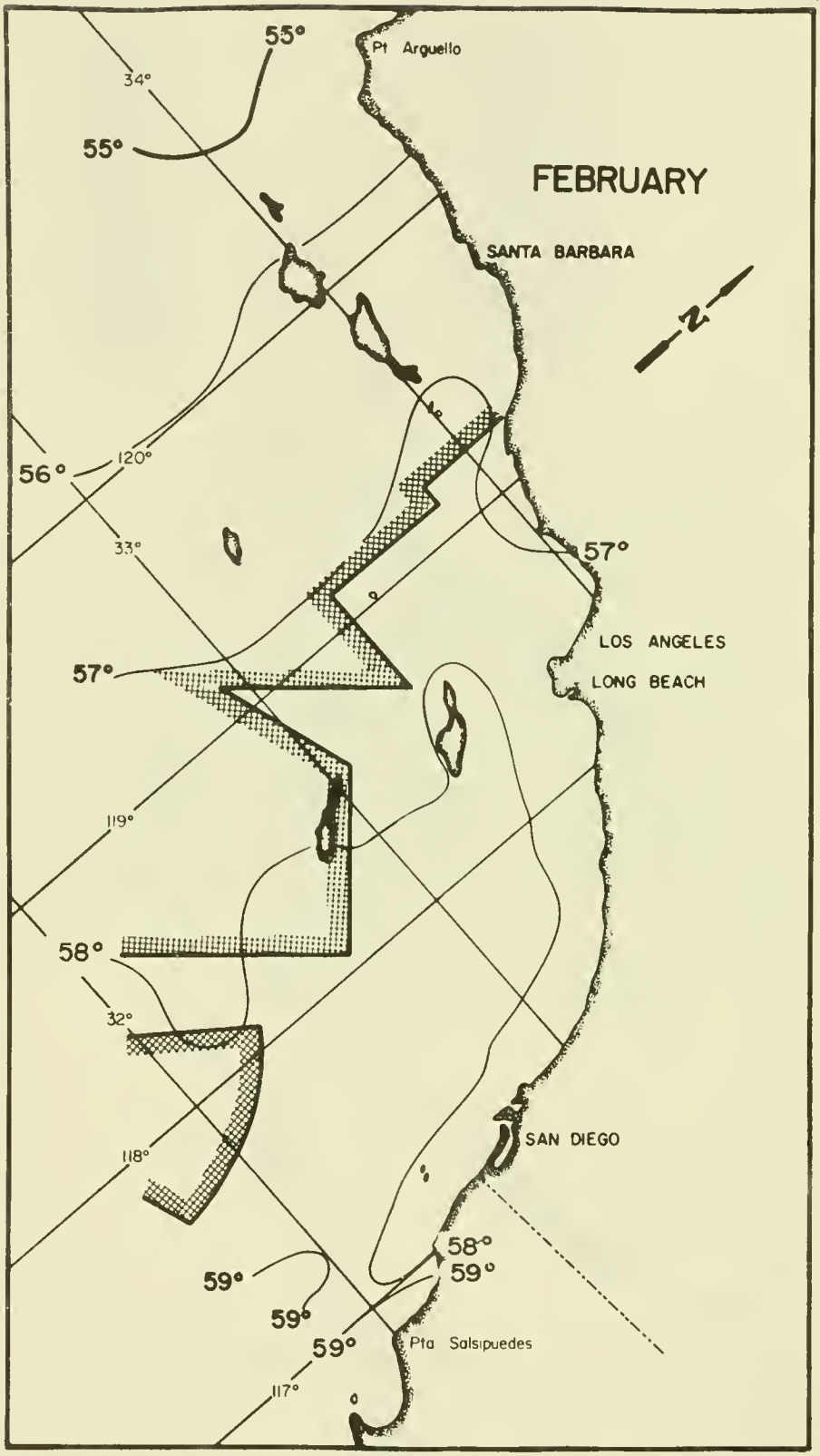



Figure 9. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

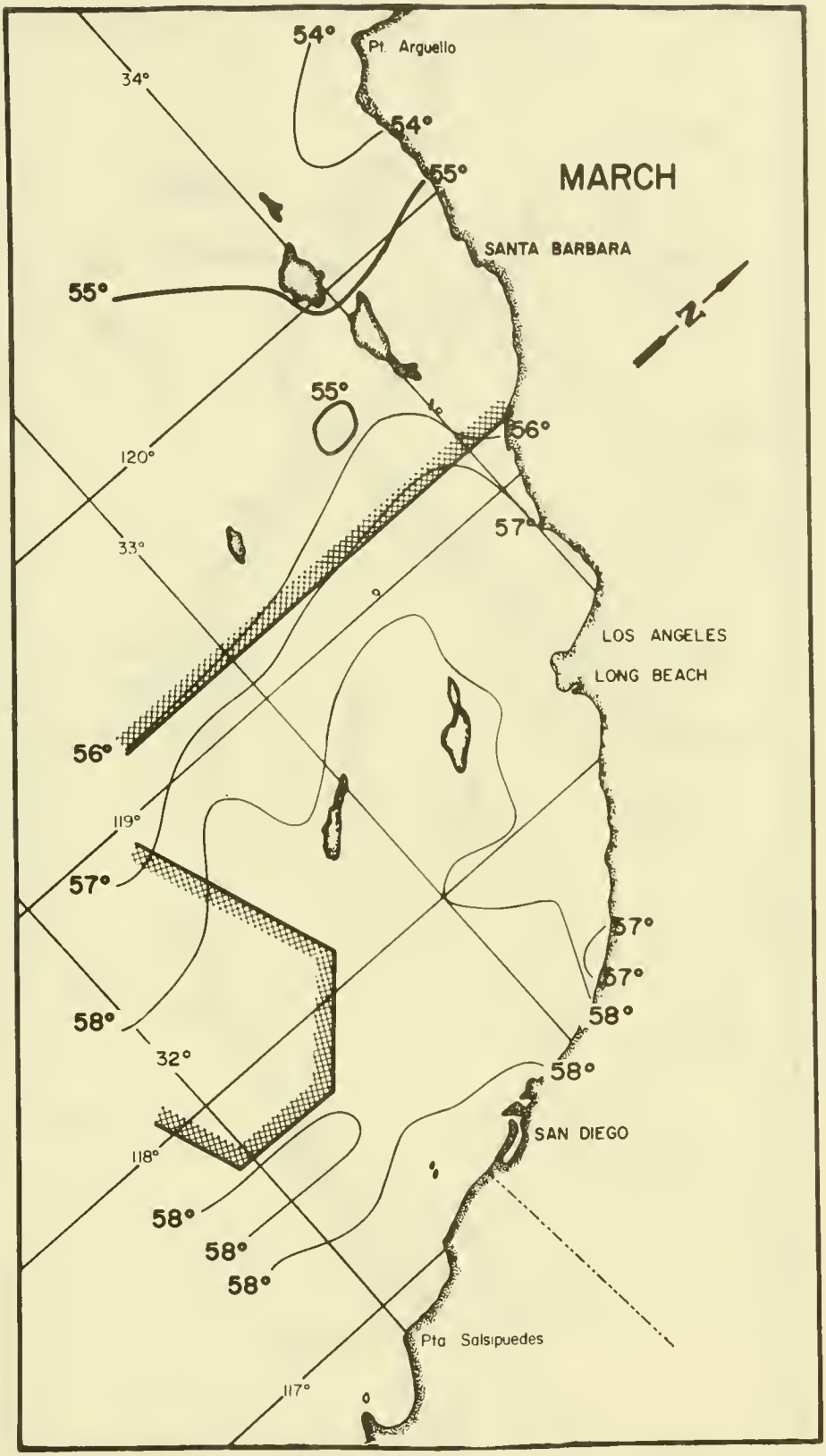



**Figure 10. Five-year mean monthly distribution of sea surface temperature (°F). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.**

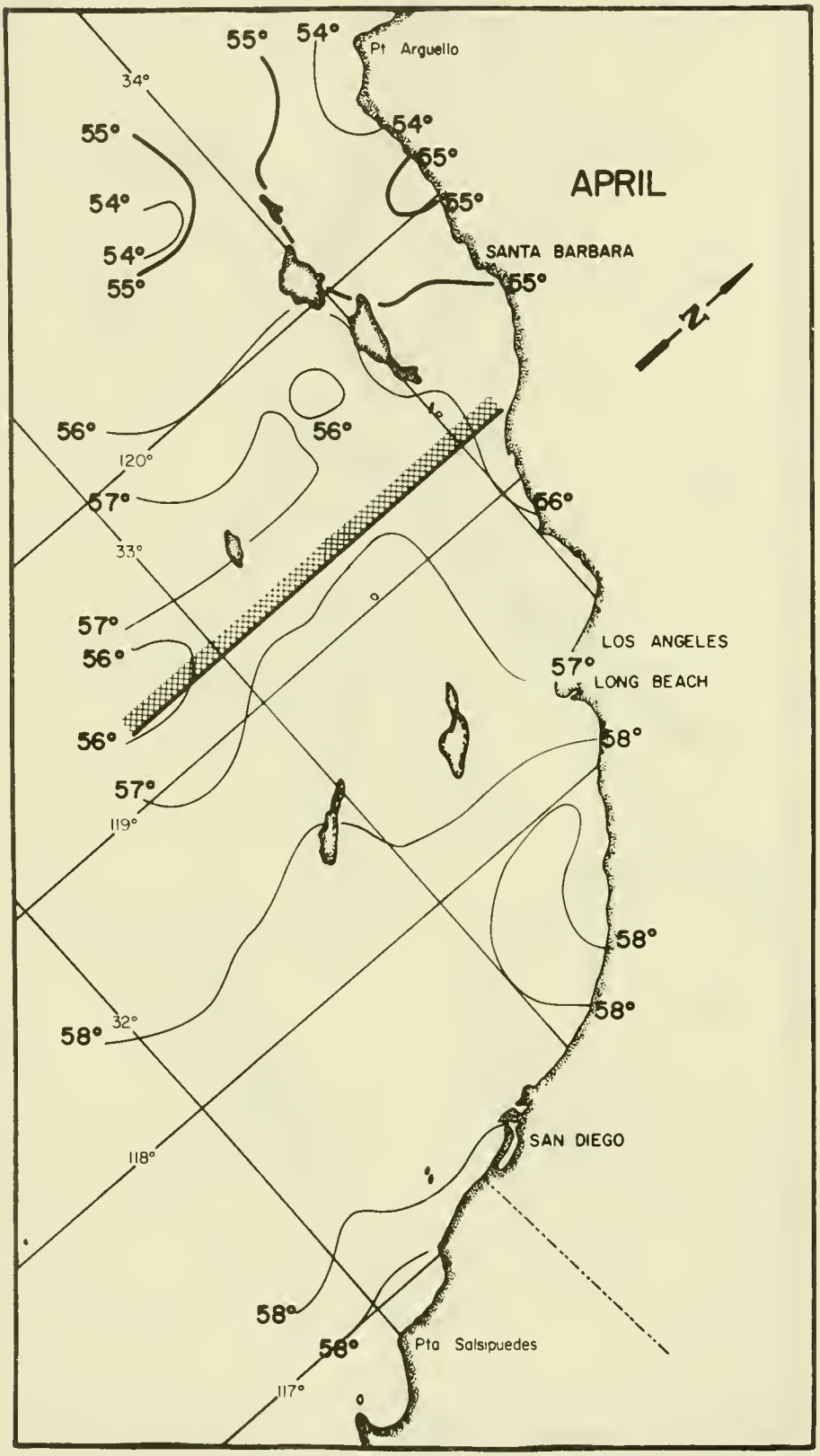



Figure 11. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy li indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

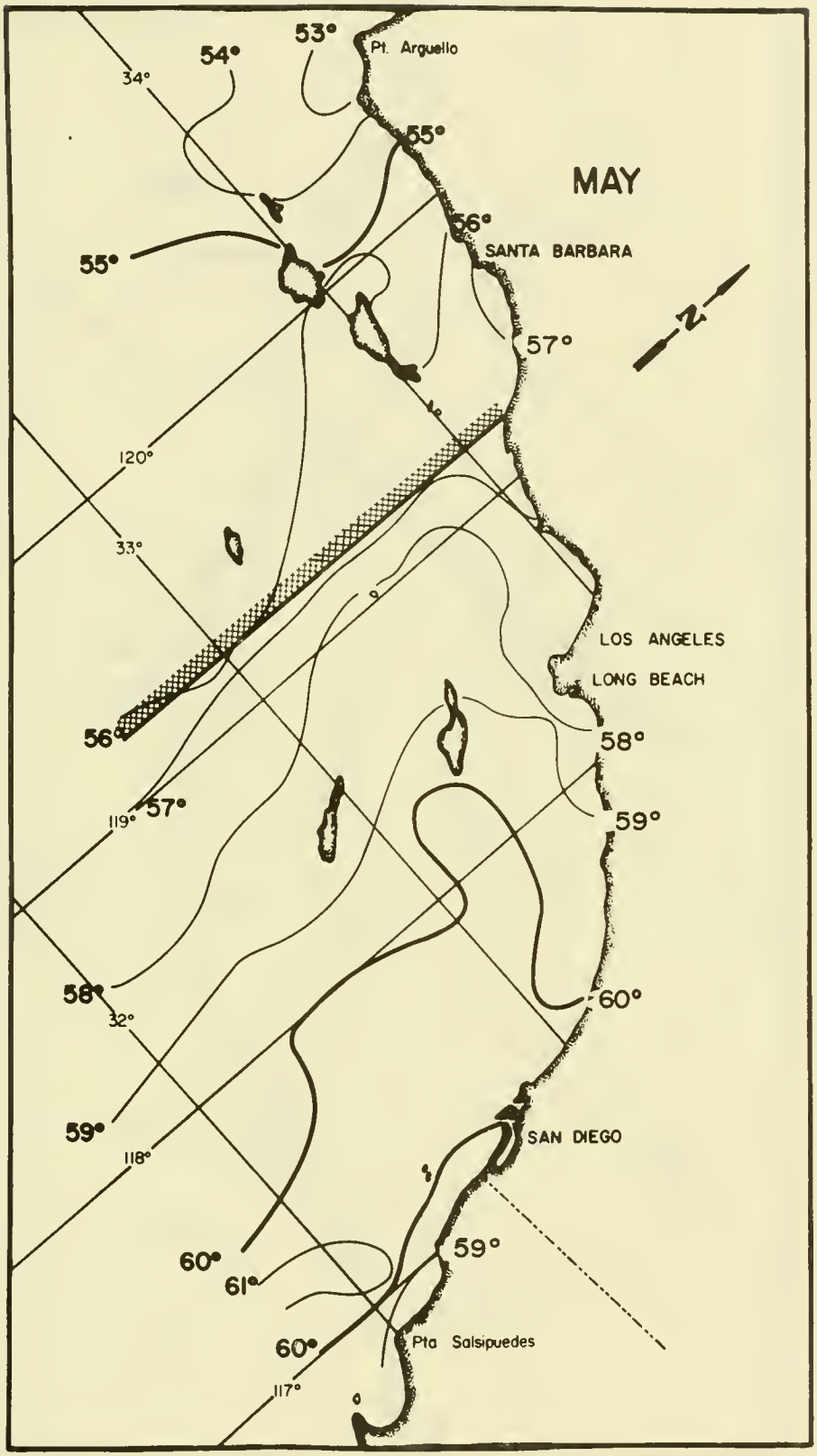



Figure 12. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

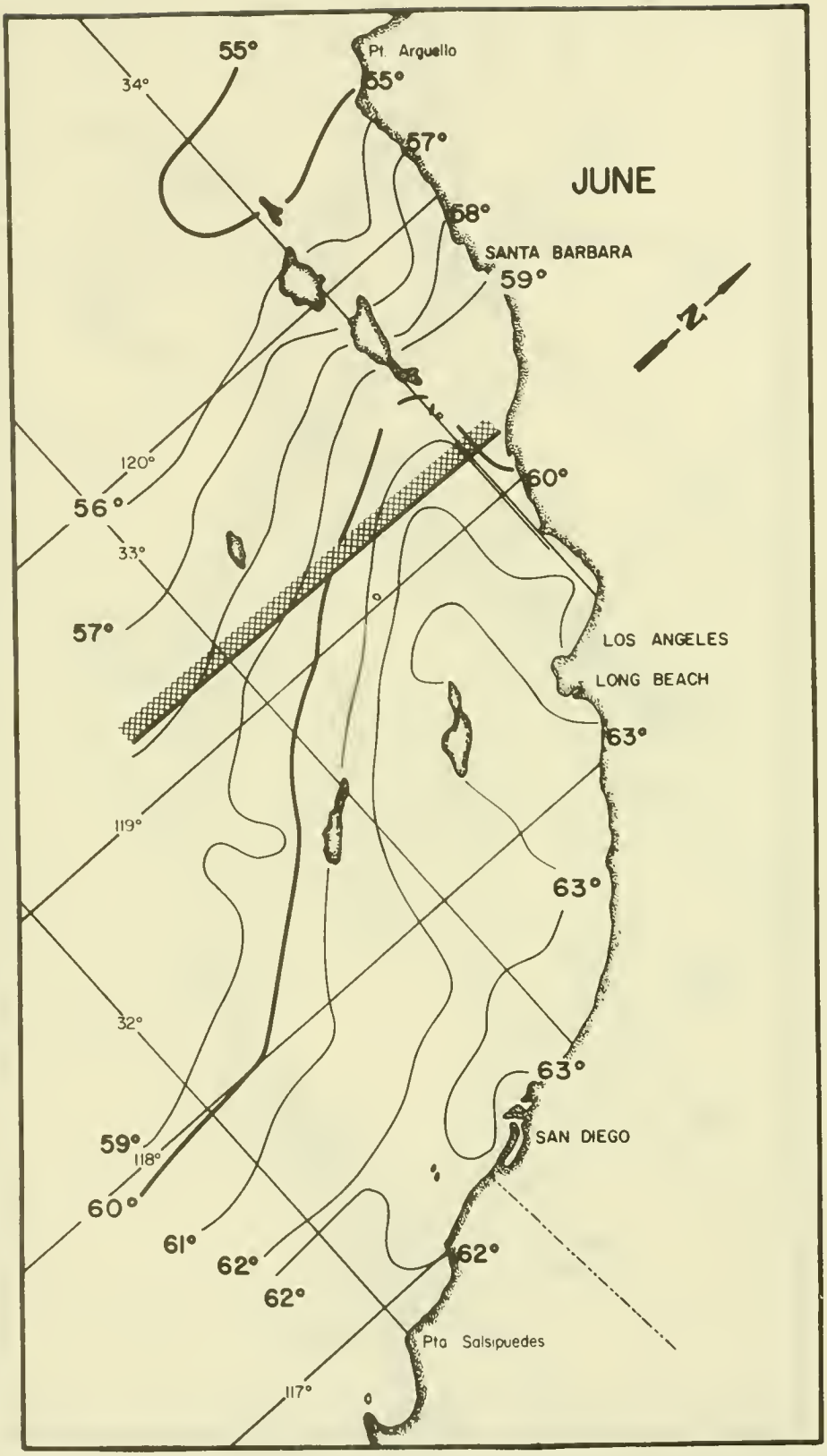



Figure 13. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

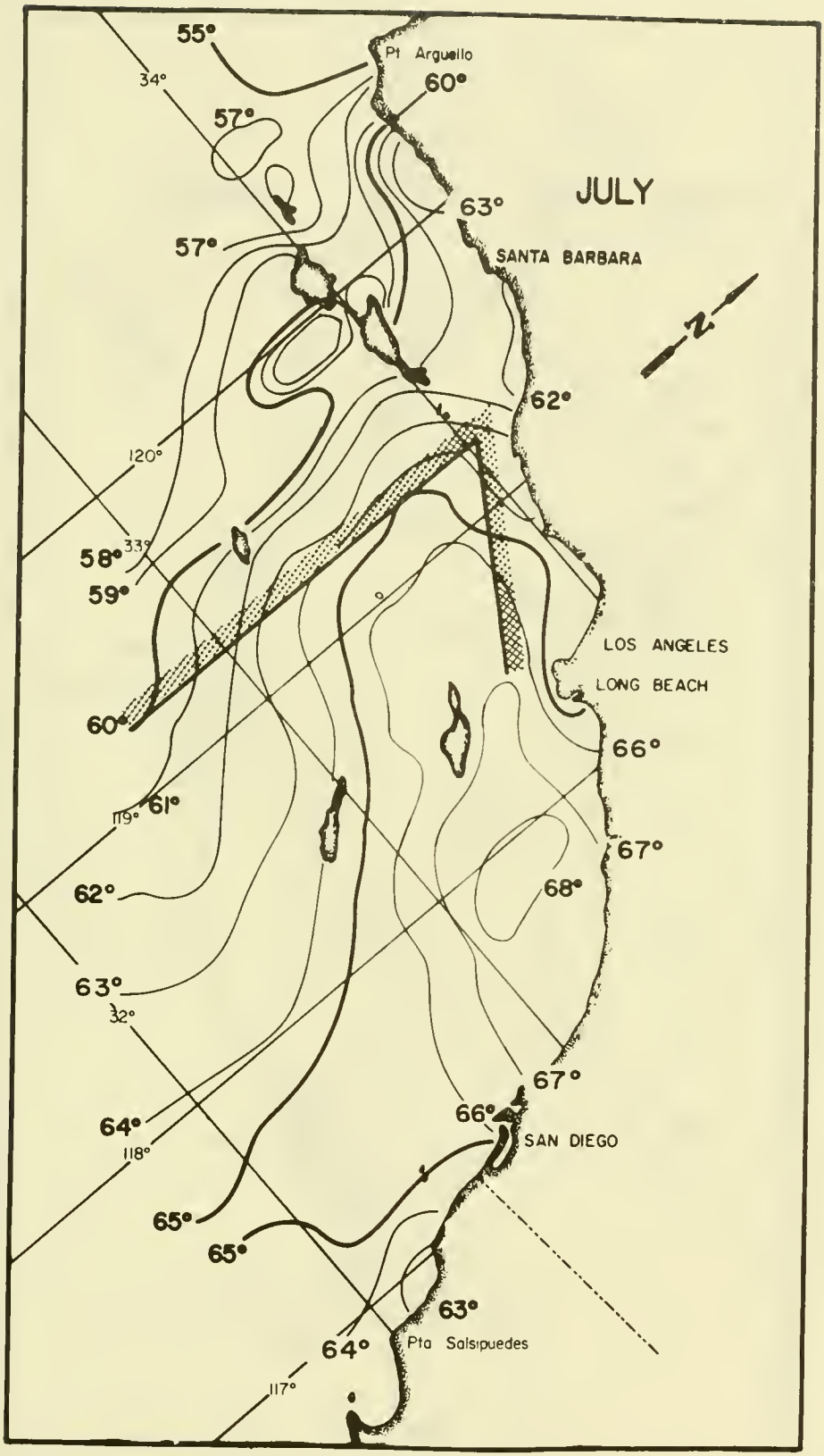



Figure 14. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

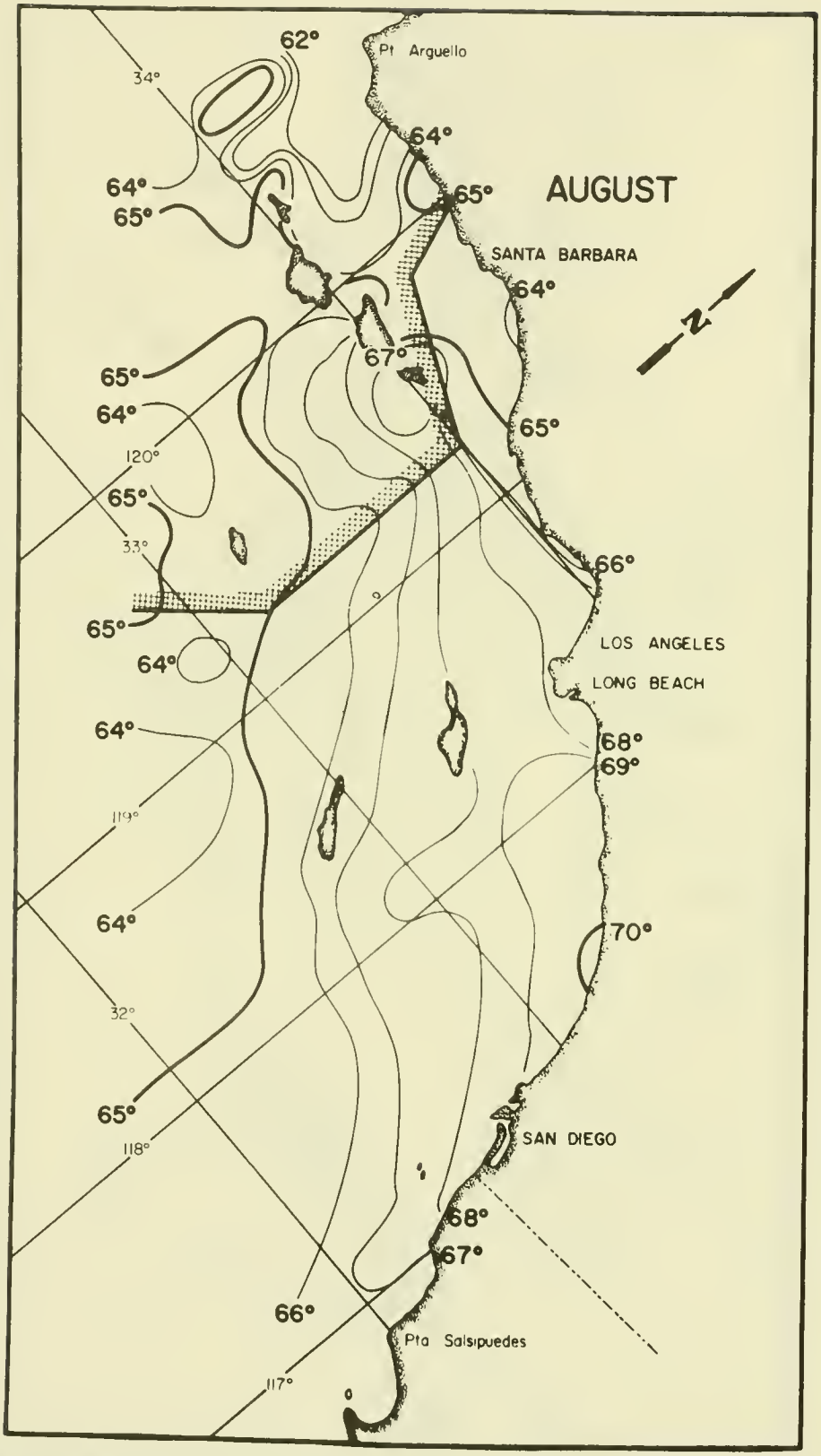



Figure 15. Five-yar mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

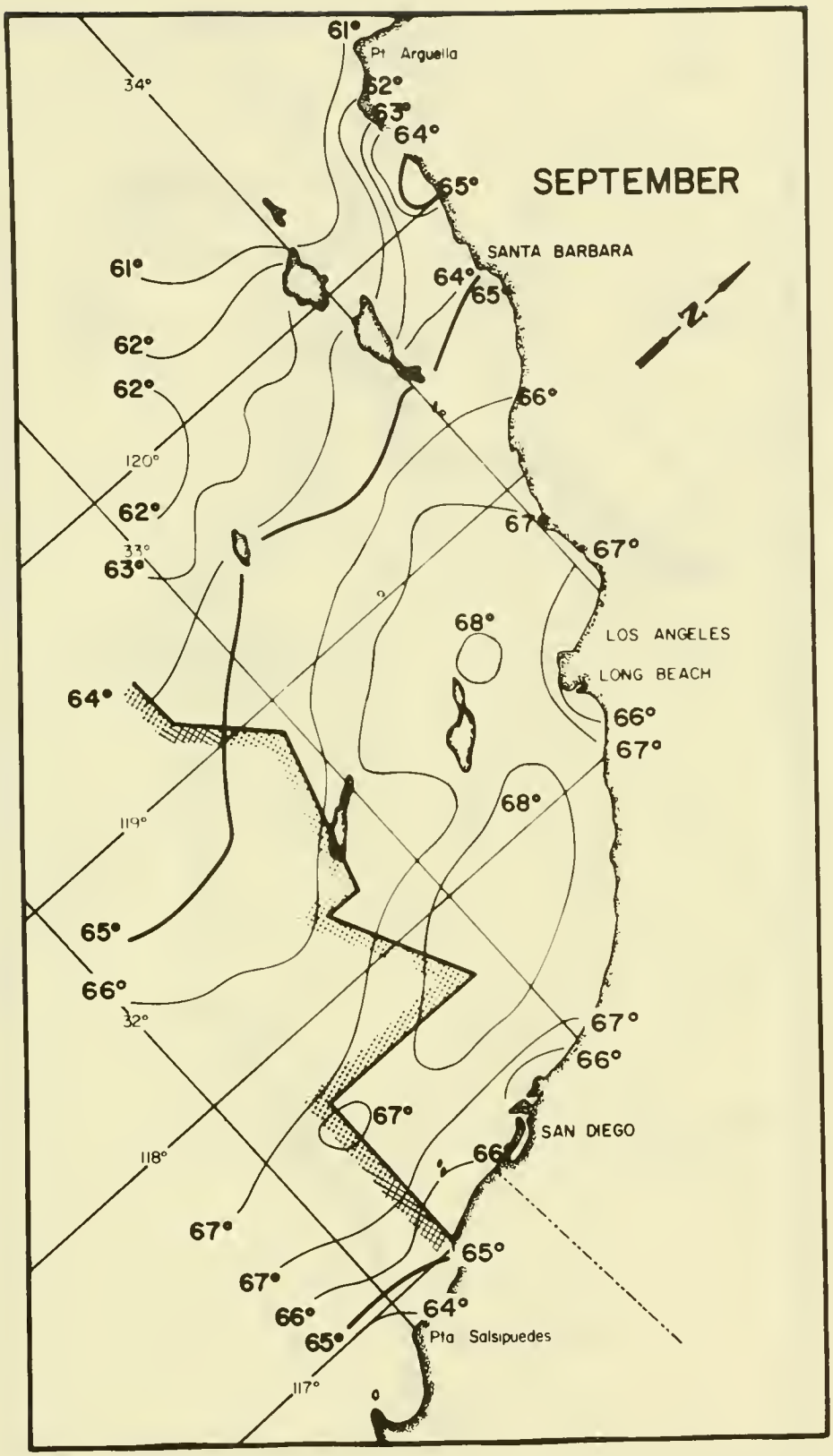



Figure 16. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

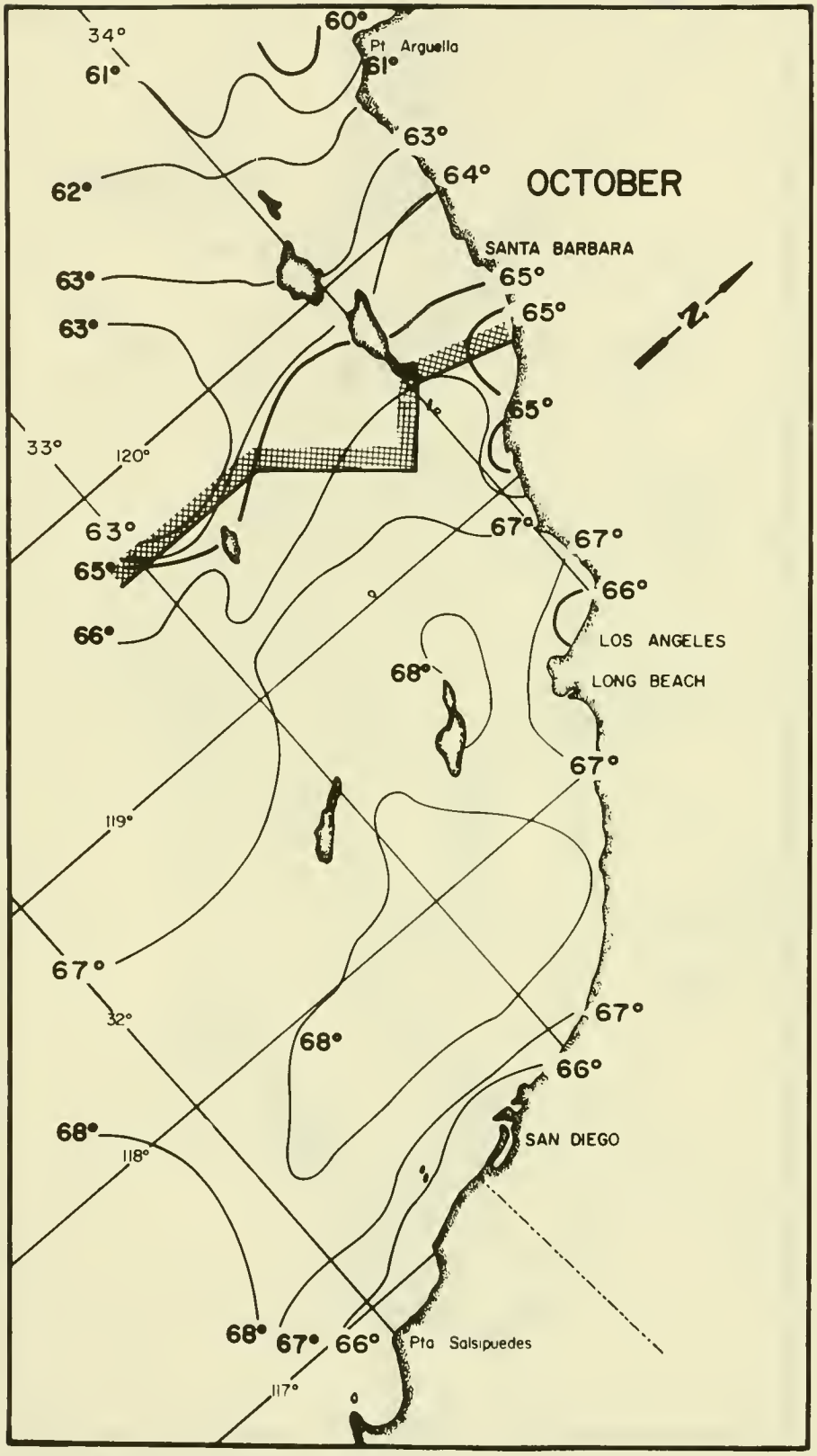



Figure 17. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

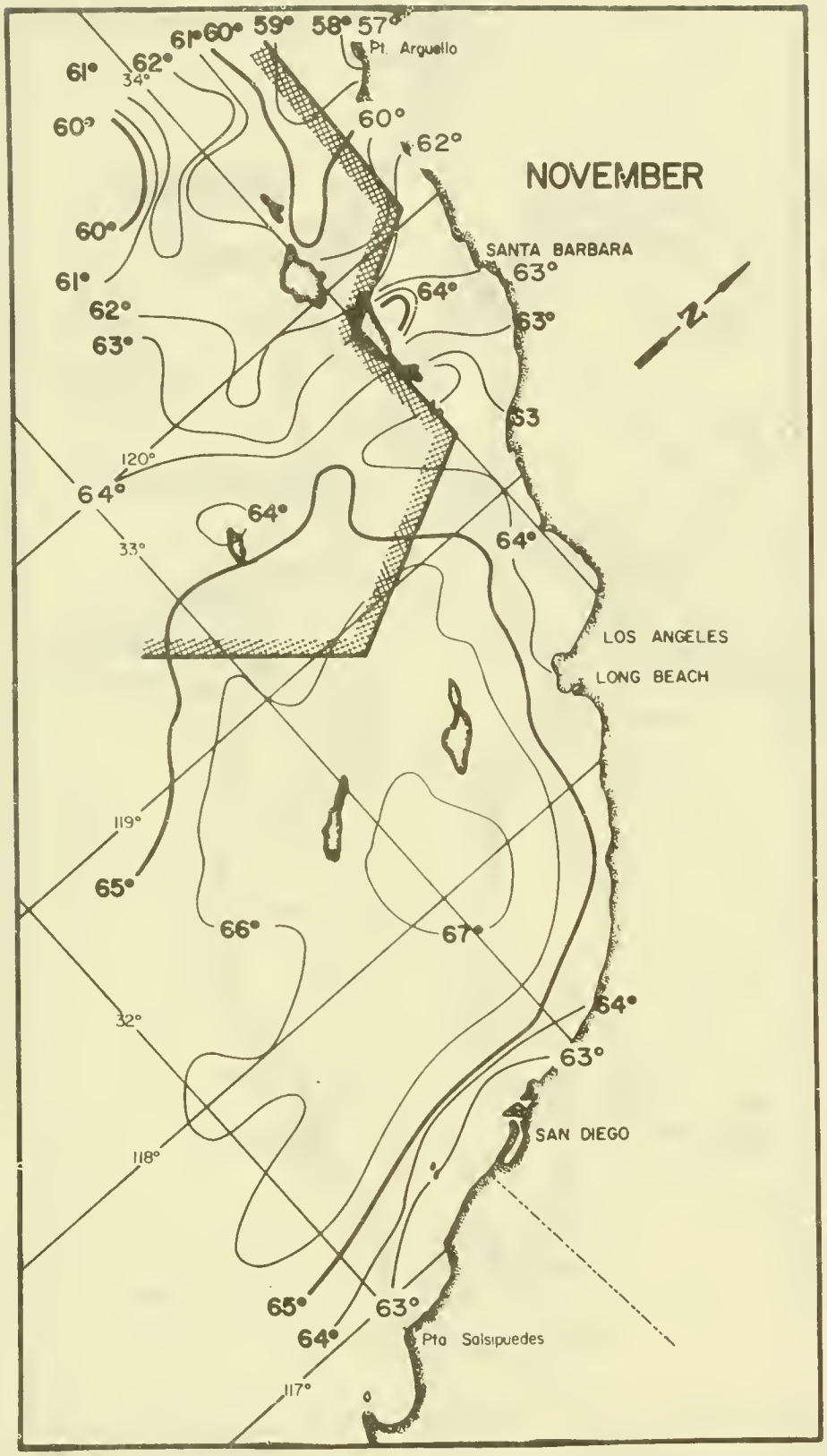



Figure 18. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

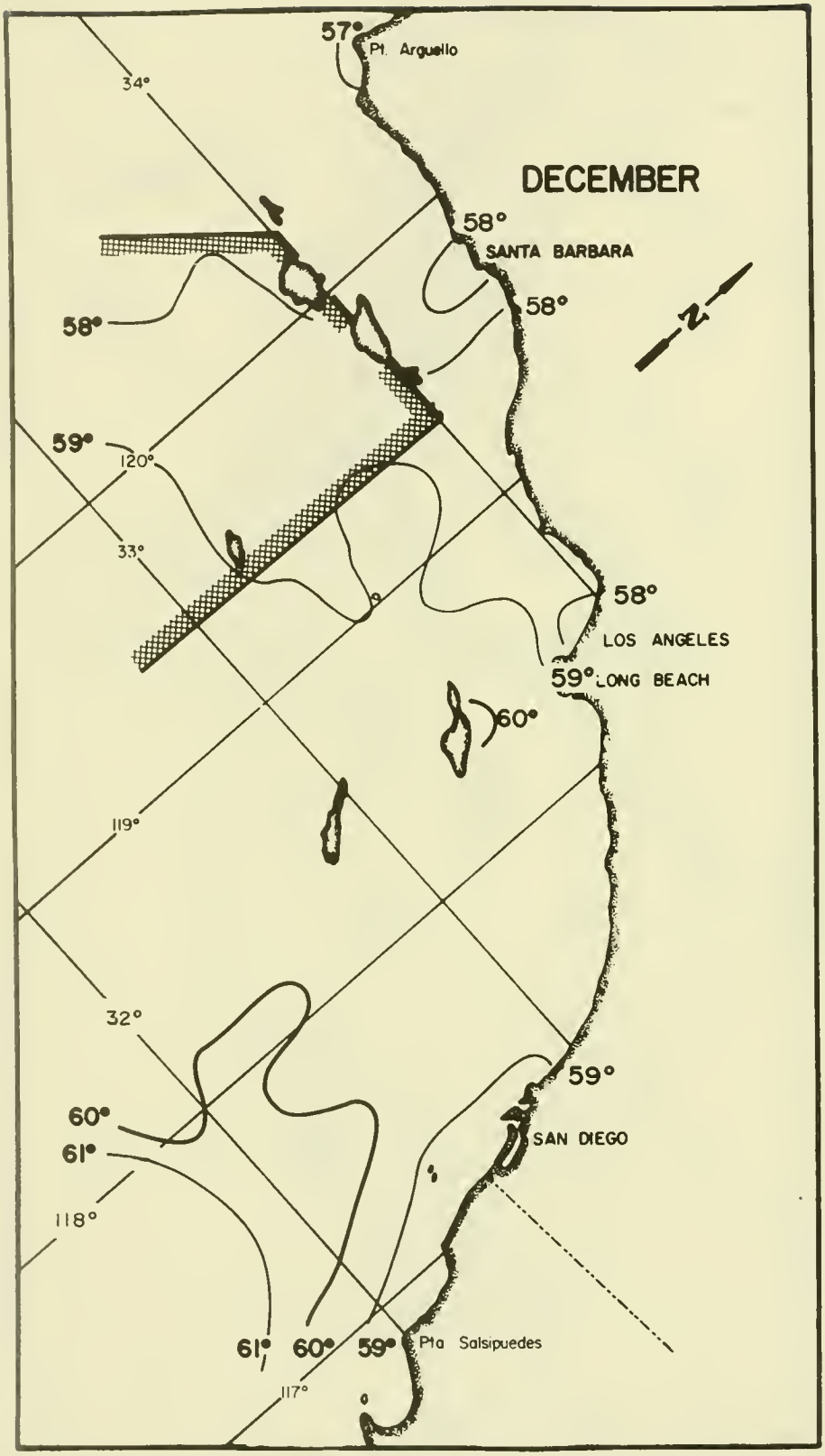



Figure 19. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

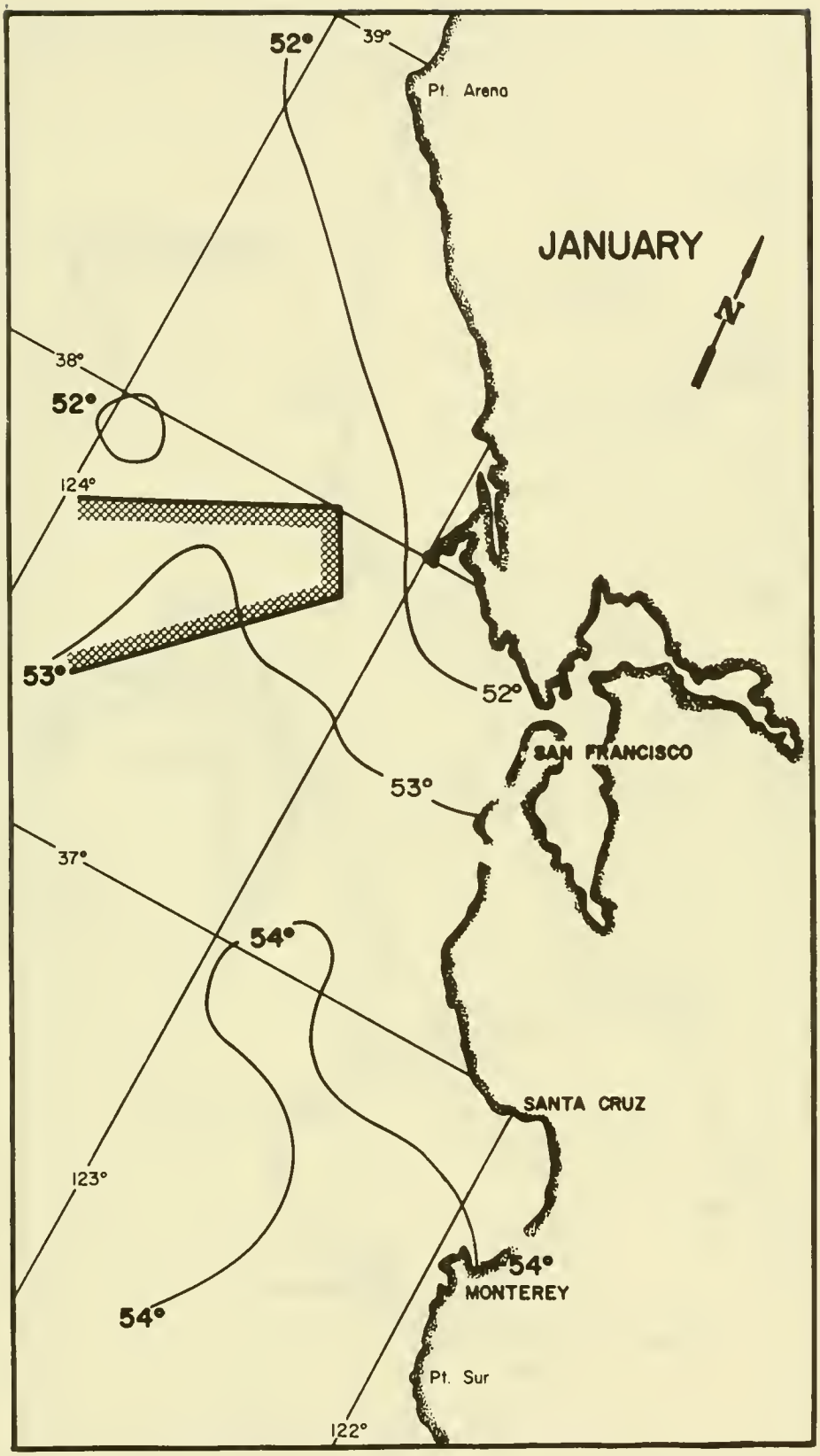



**Figure 20.** Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

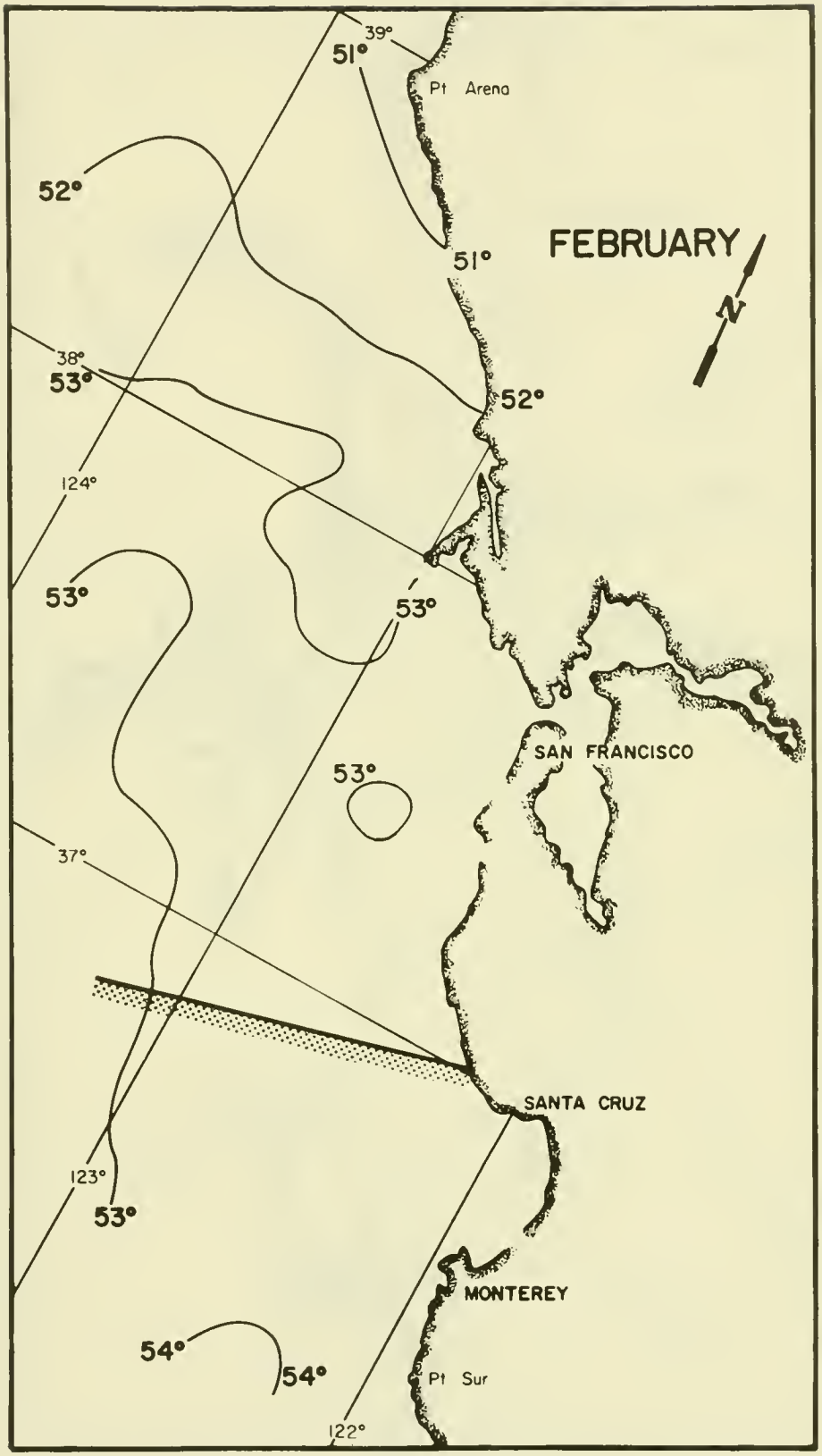



Figure 21. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

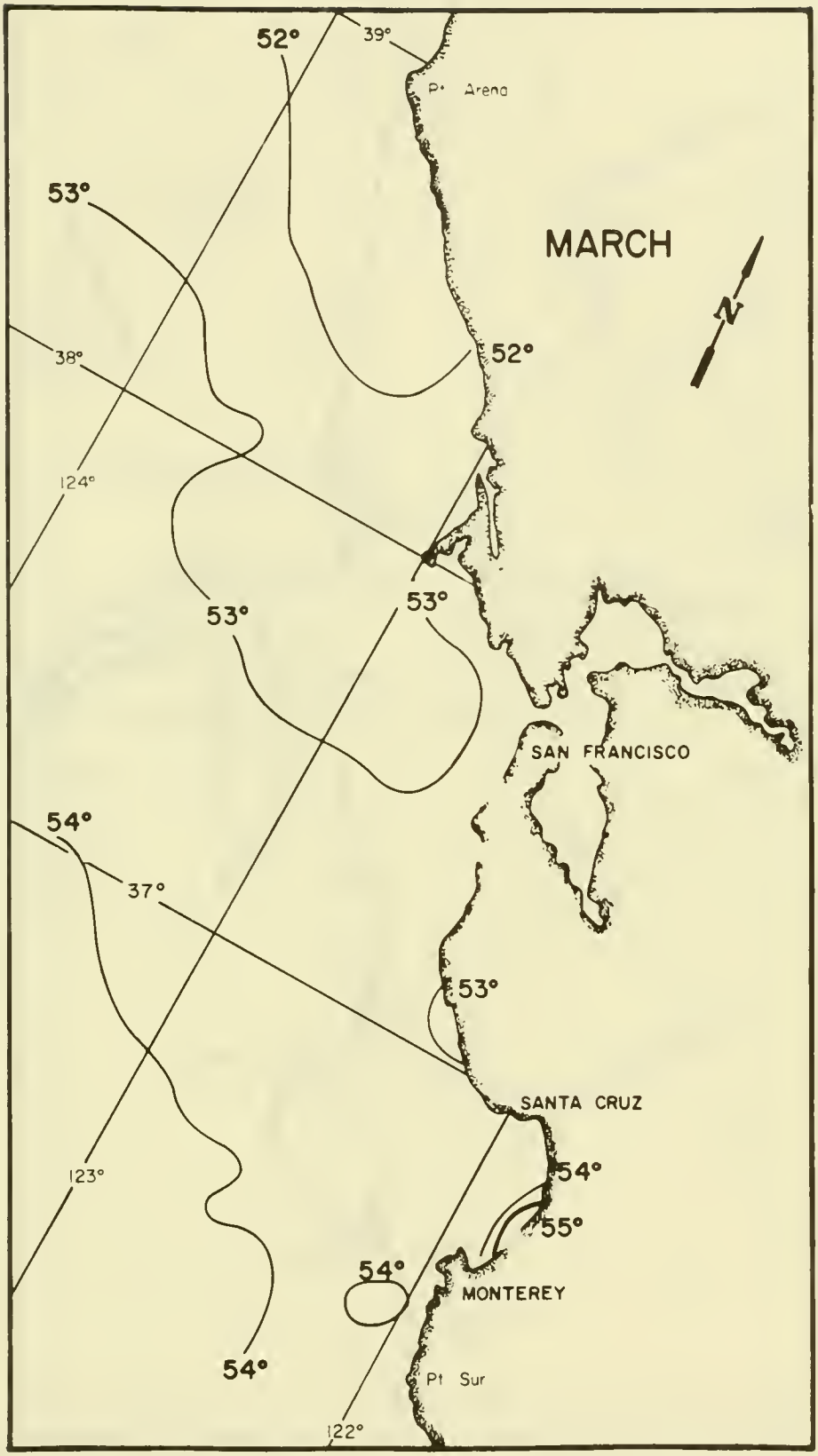



Figure 22. Five-year mean monthly distribution of sea surface temperature (°F.).

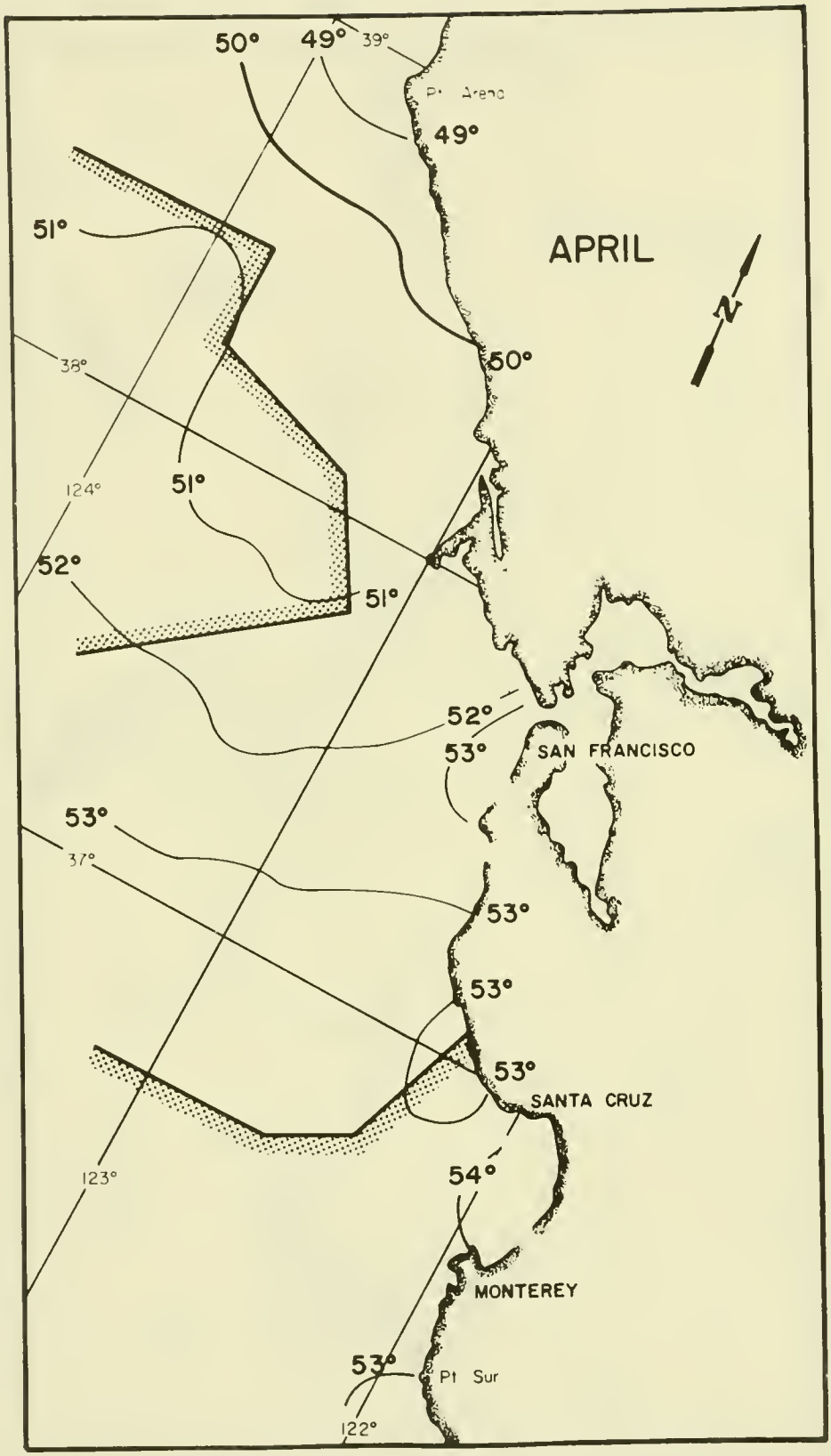



Figure 23. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

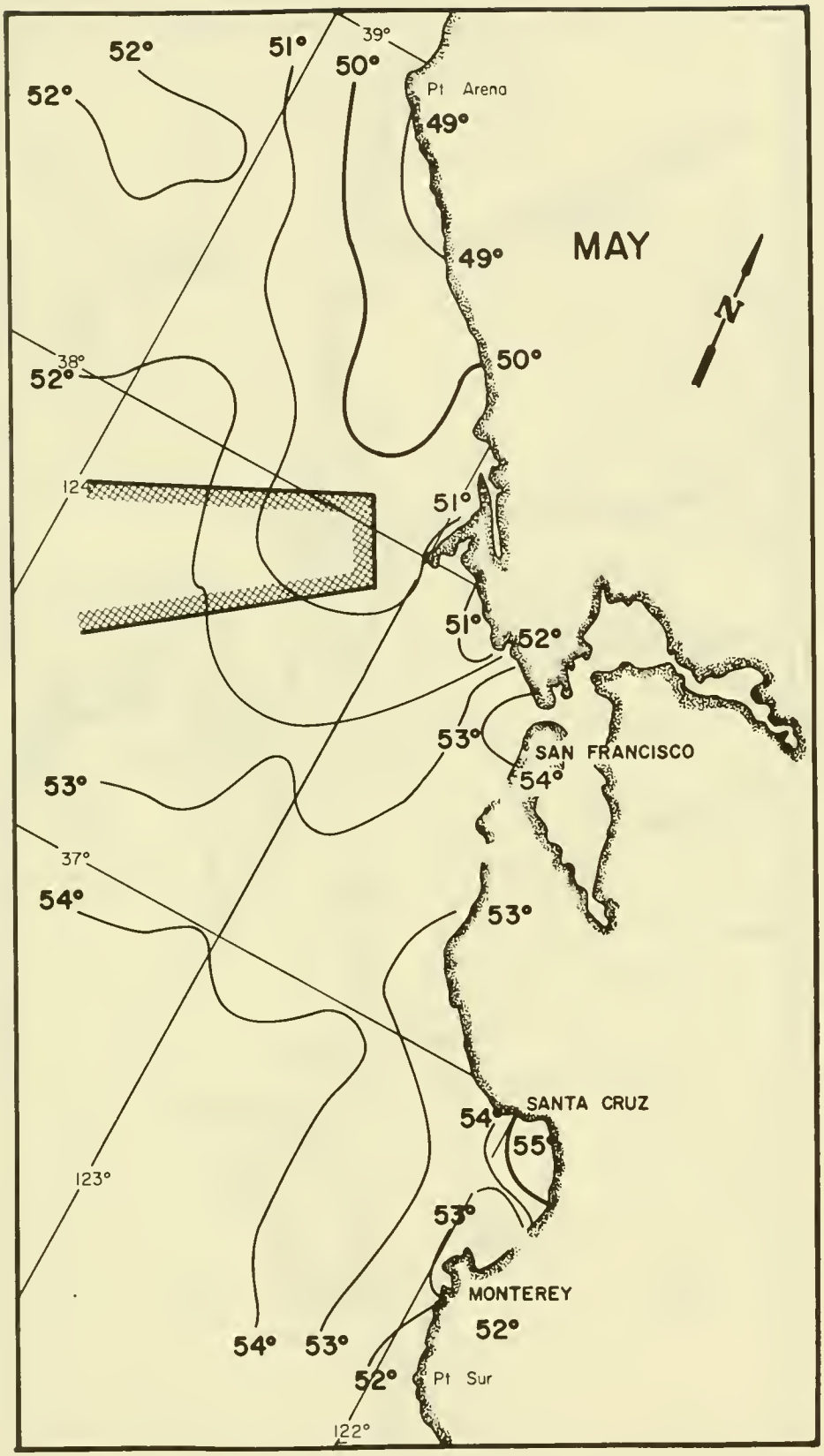



Figure 24. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

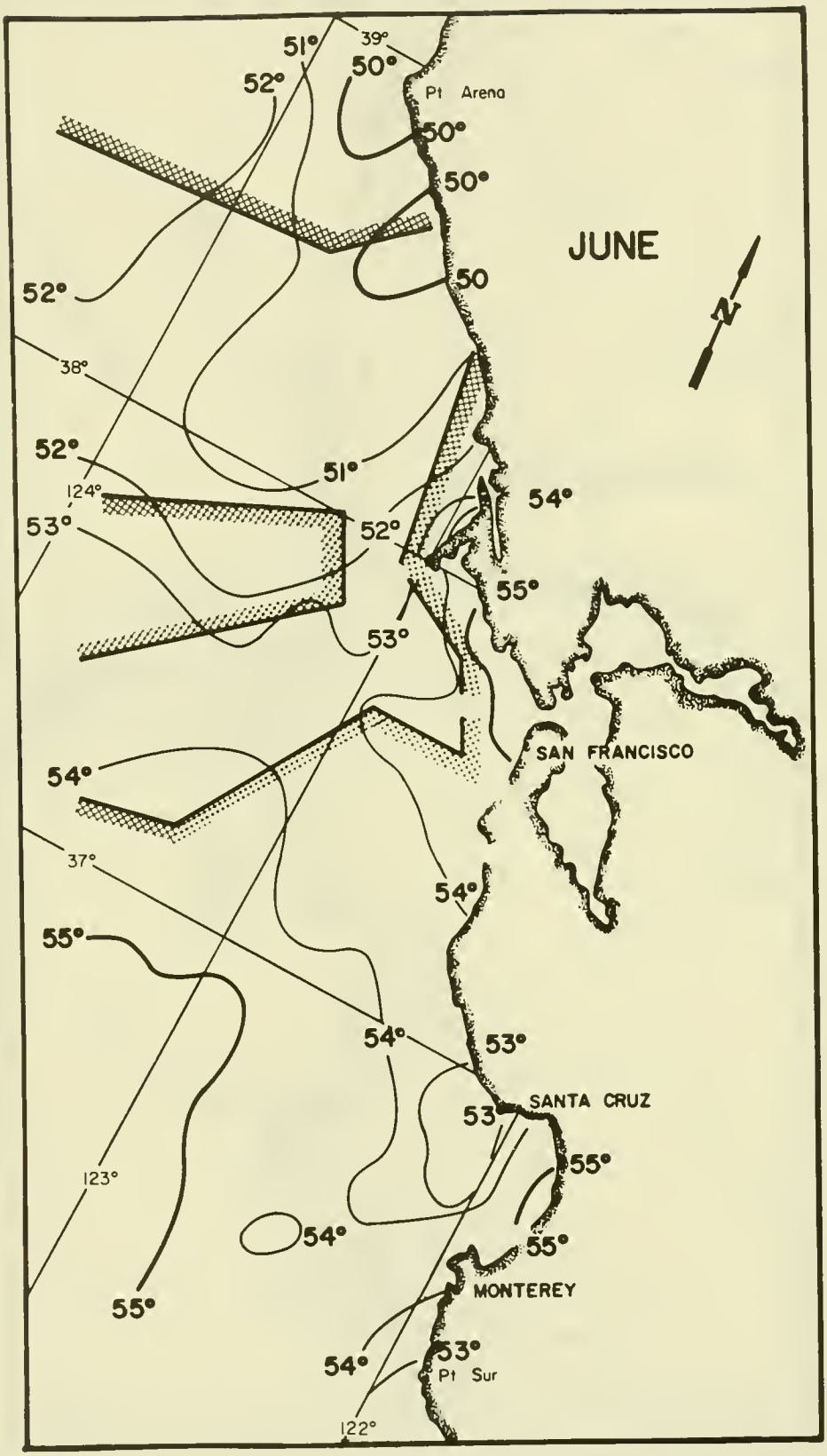



Figure 25. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

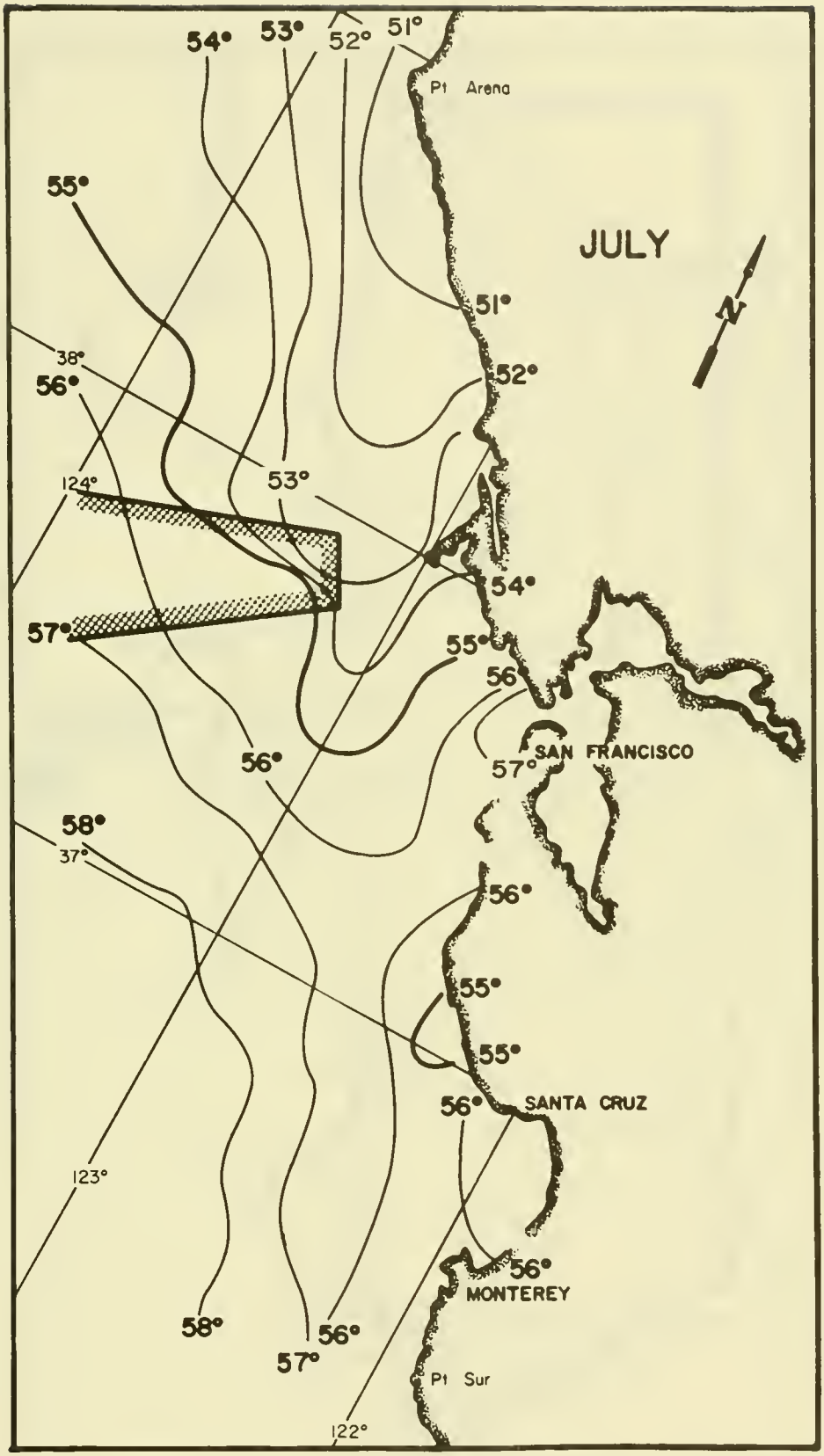



**Figure 26. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.**

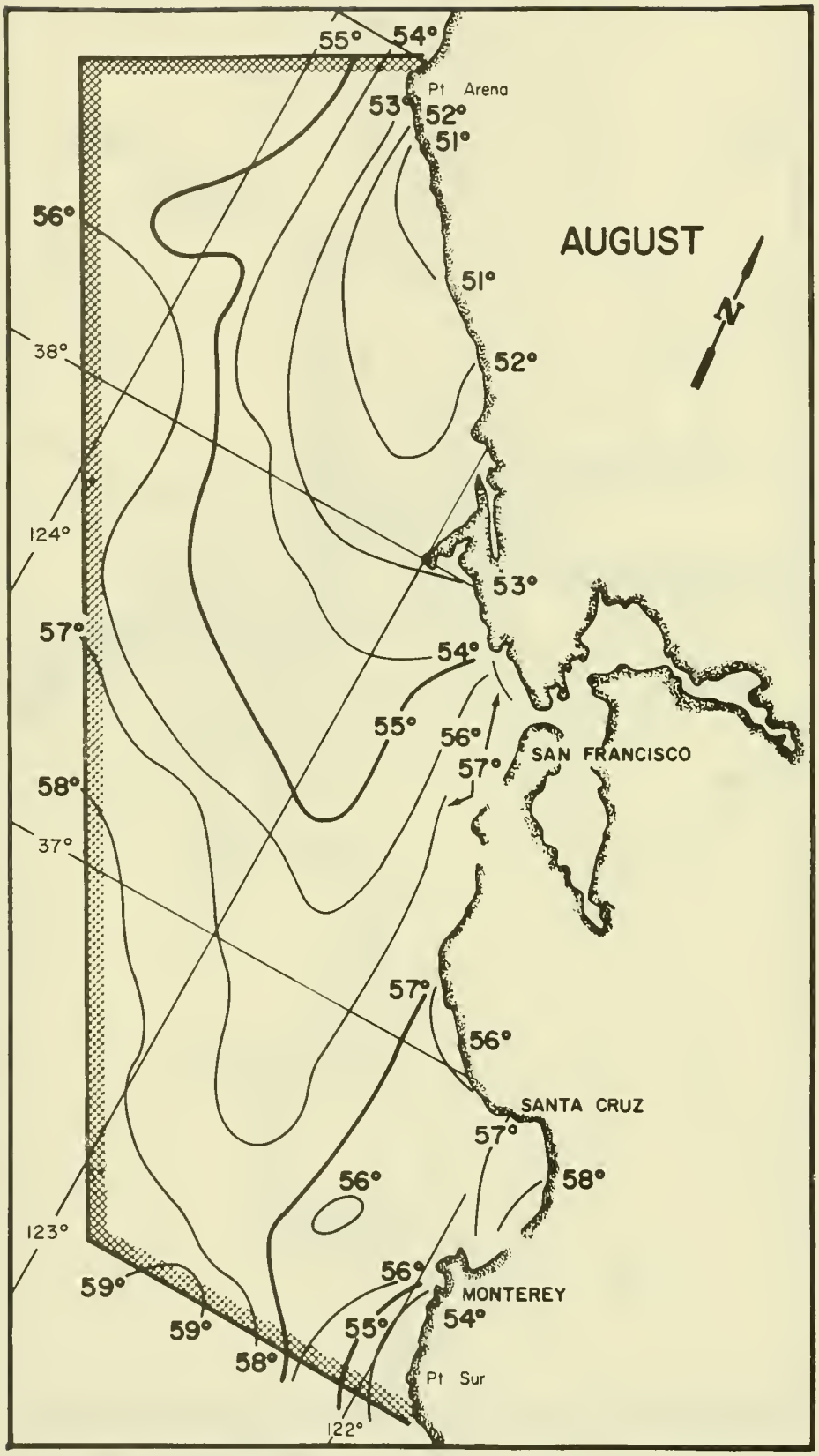



Figure 27. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

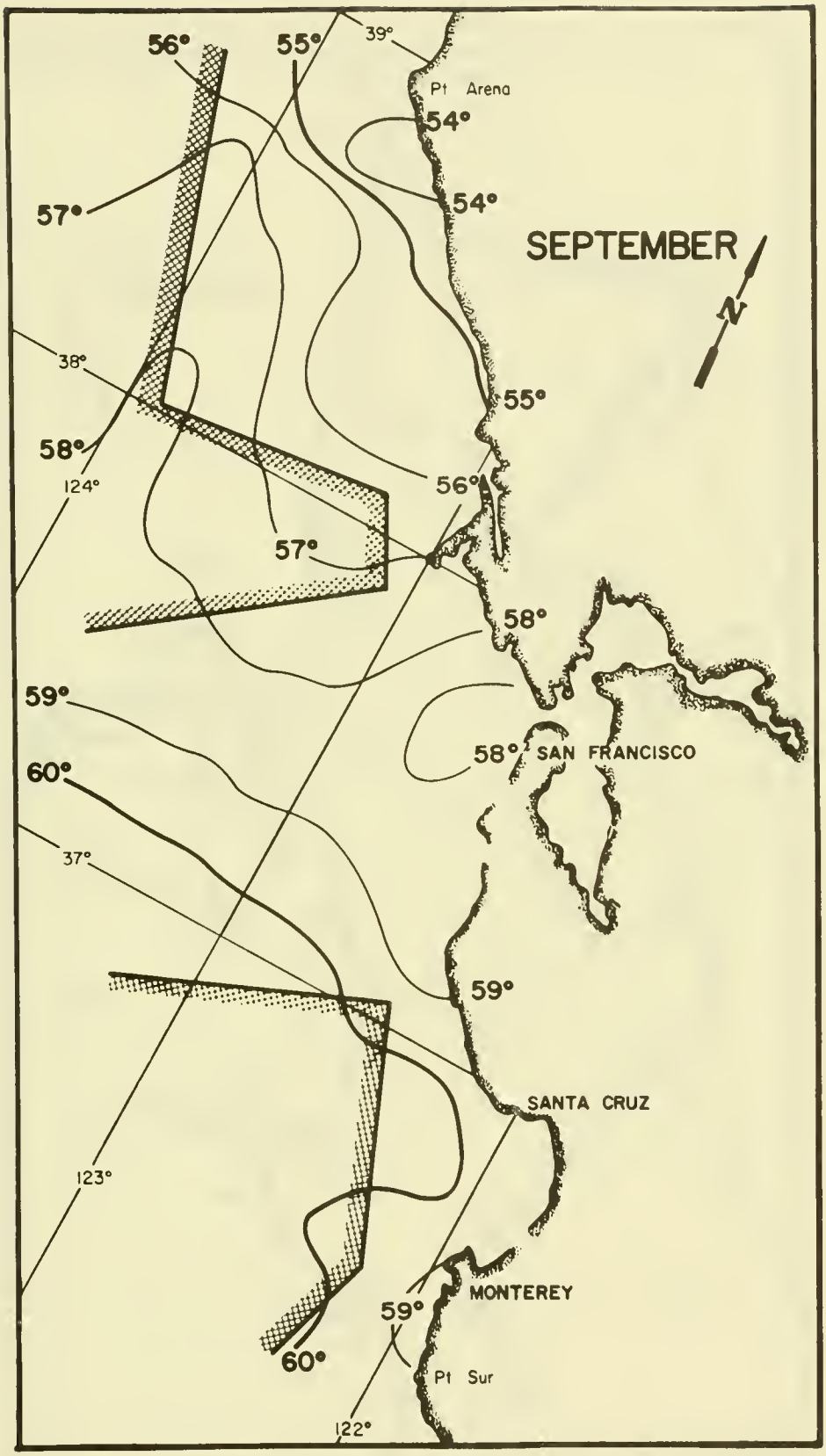



**Figure 28.** Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

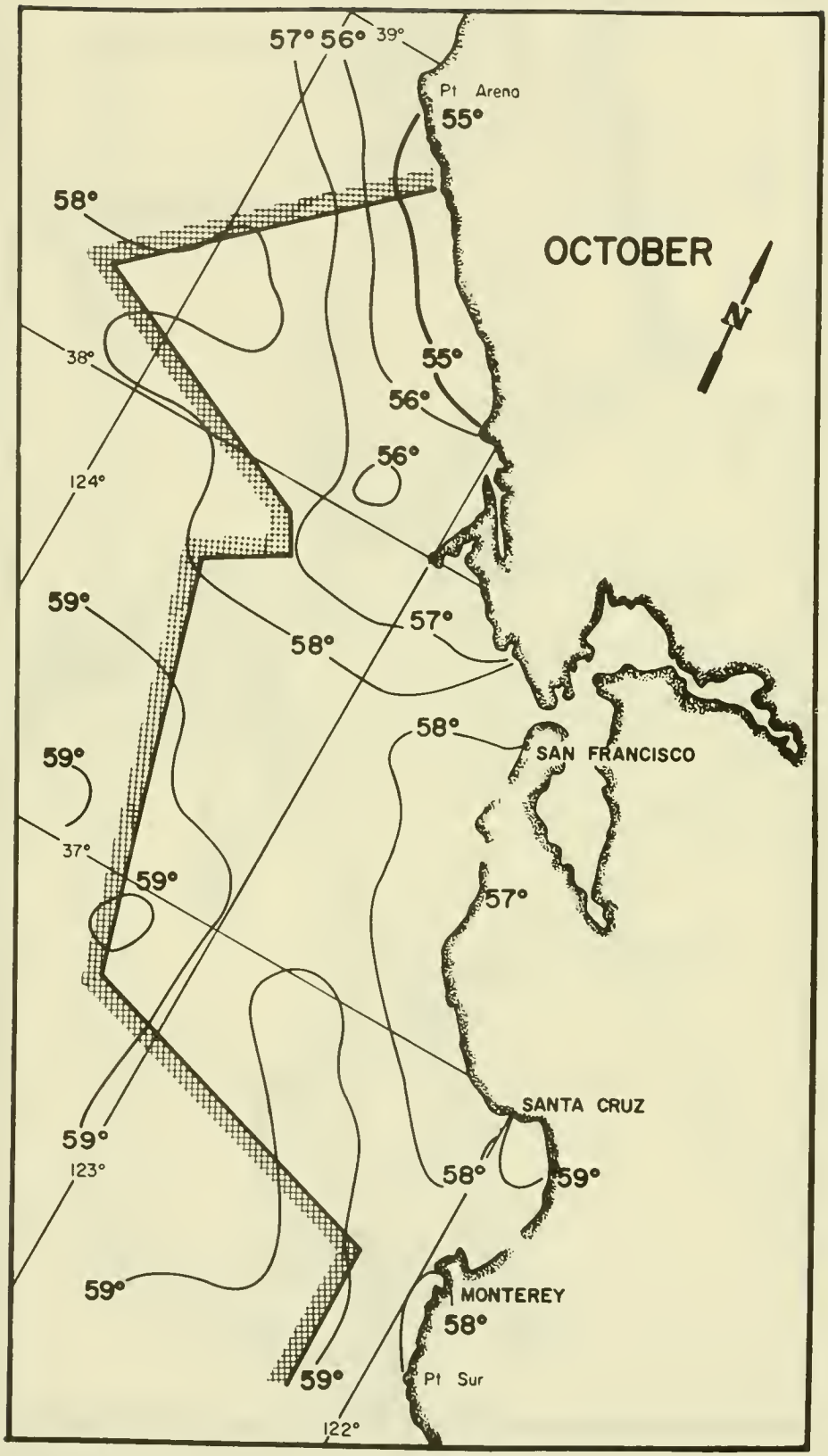



Figure 29. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

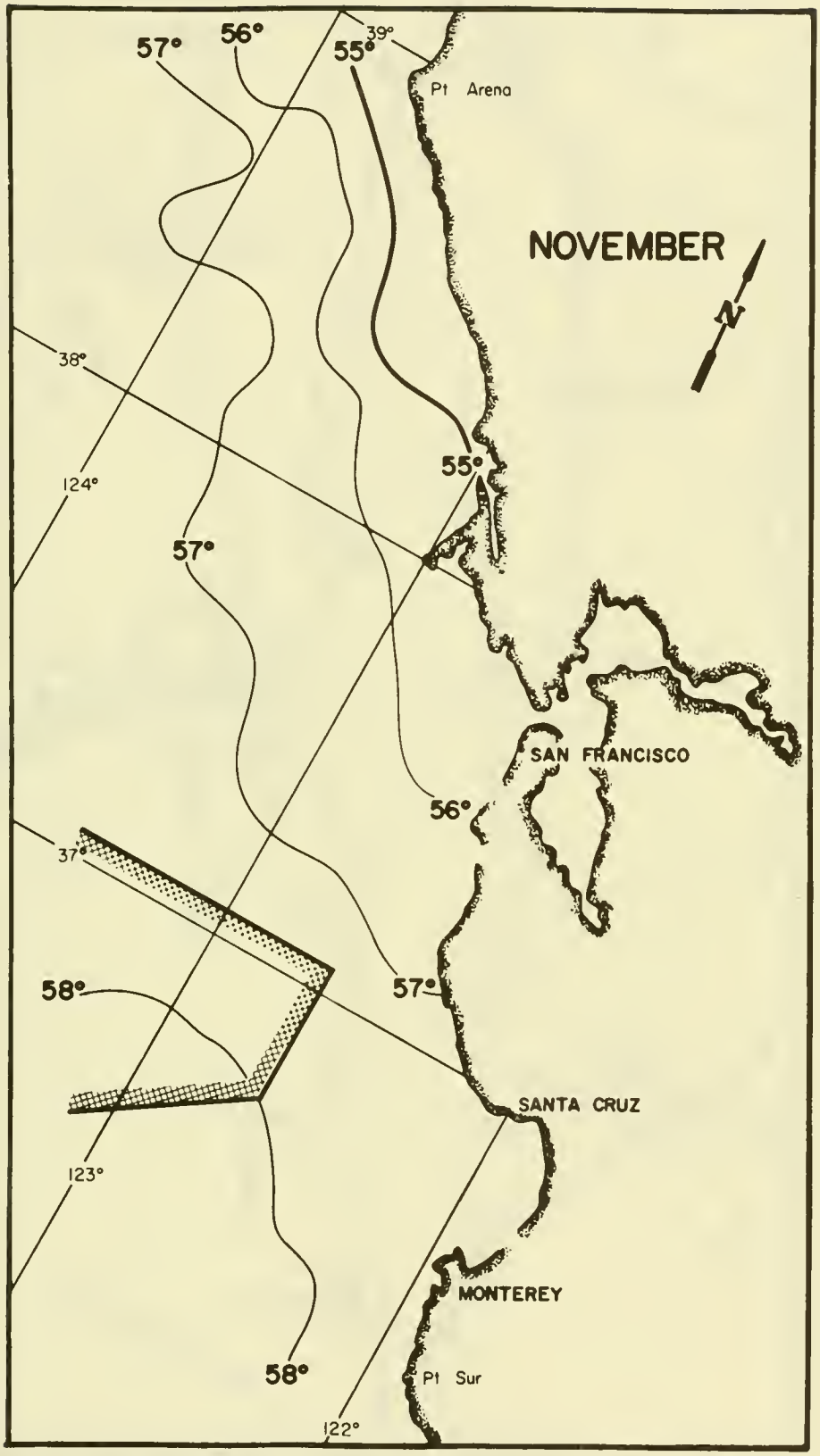



Figure 30. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

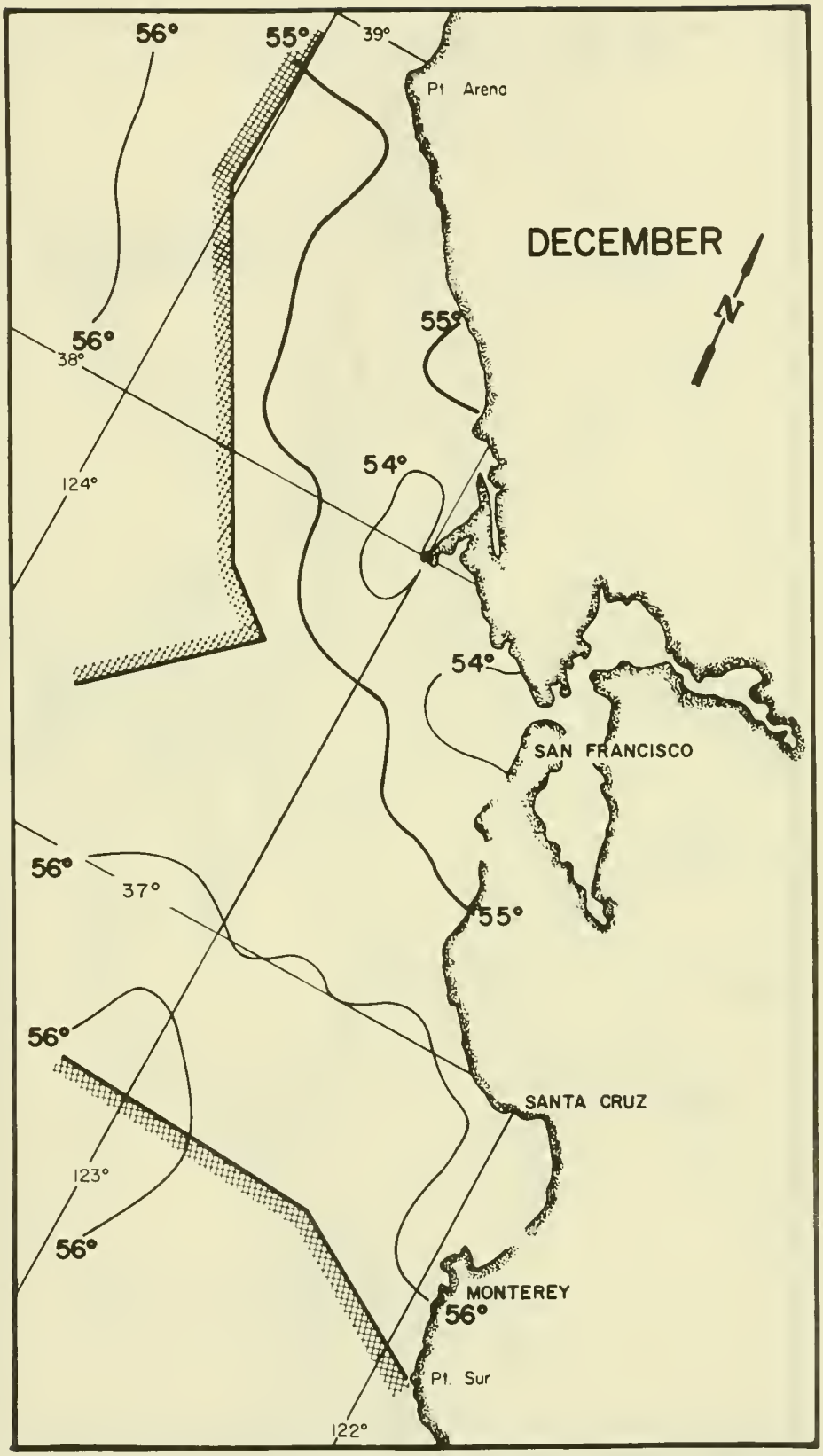



Figure 31. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

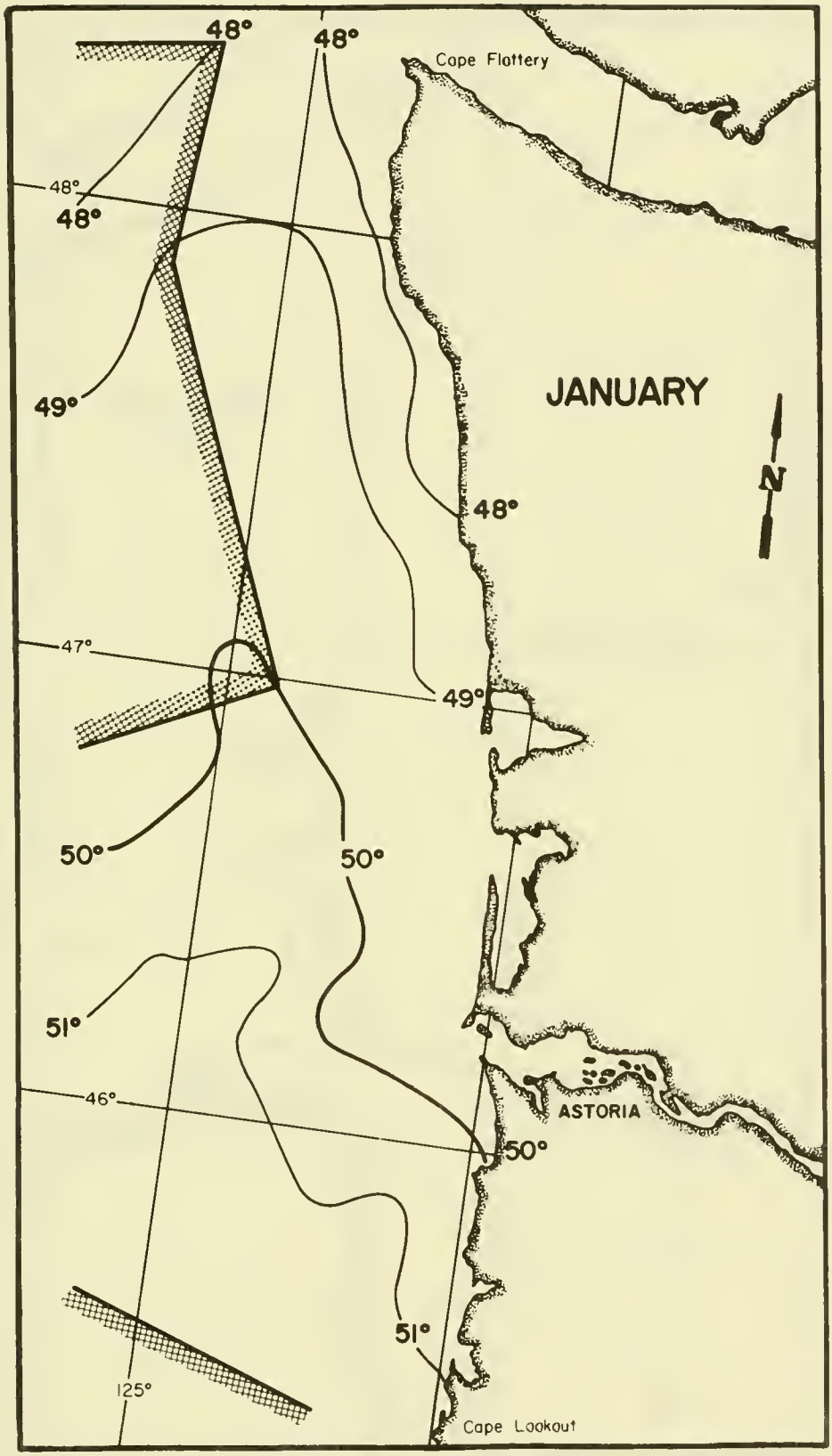



**Figure 32.** Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

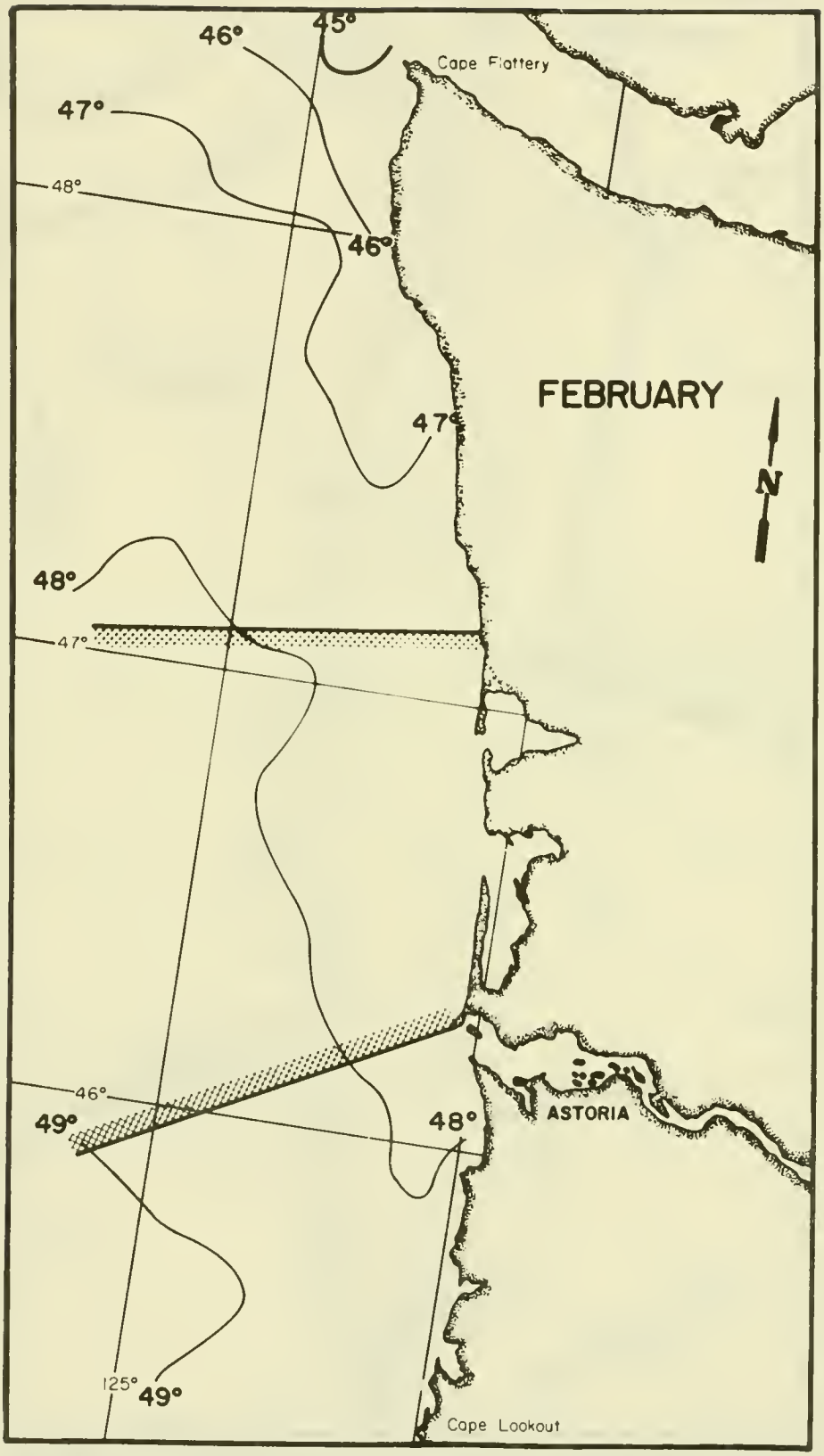



Figure 33. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

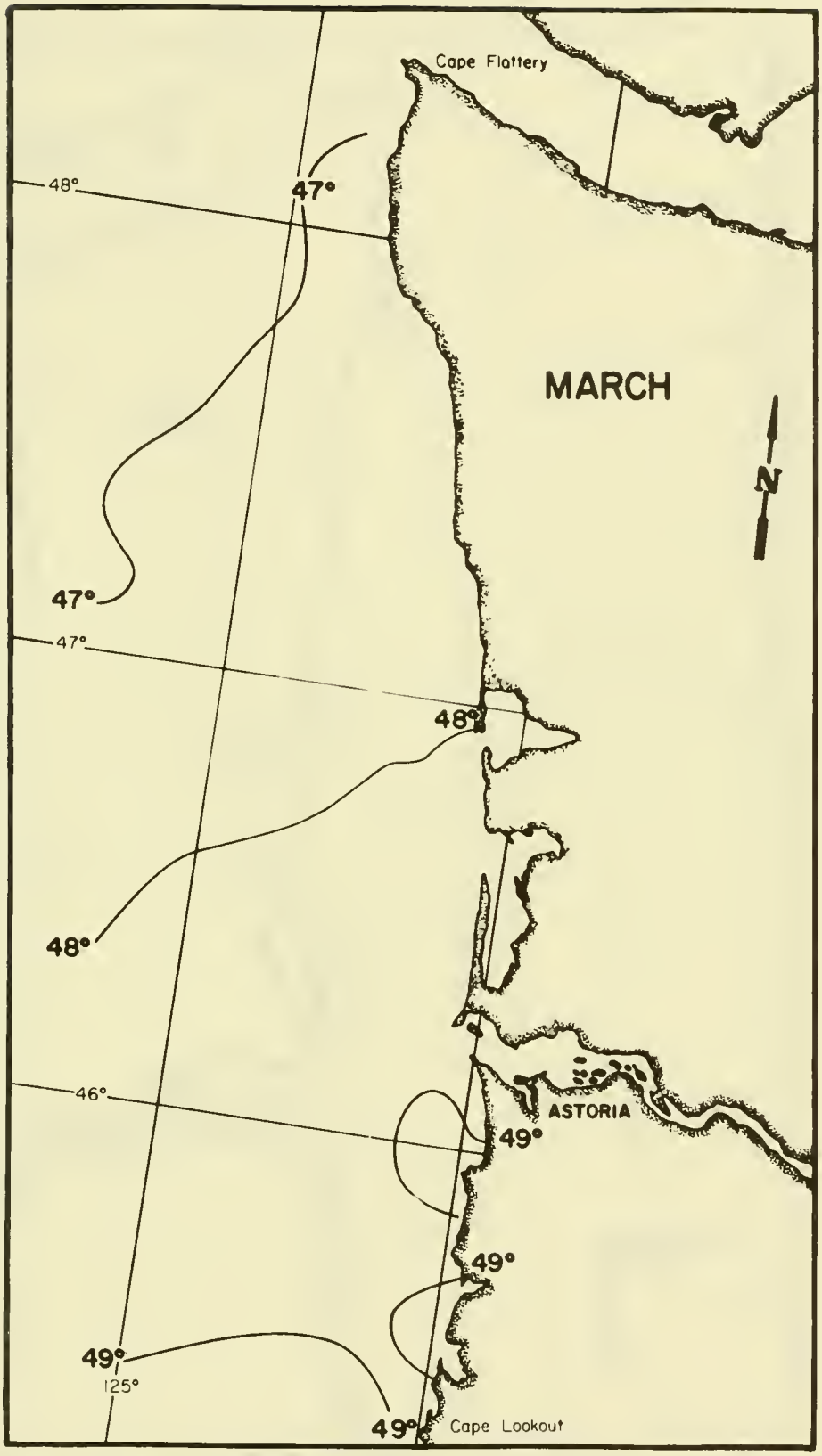



Figure 34. Five-year mean monthly distribution of sea surface temperature (°F.).

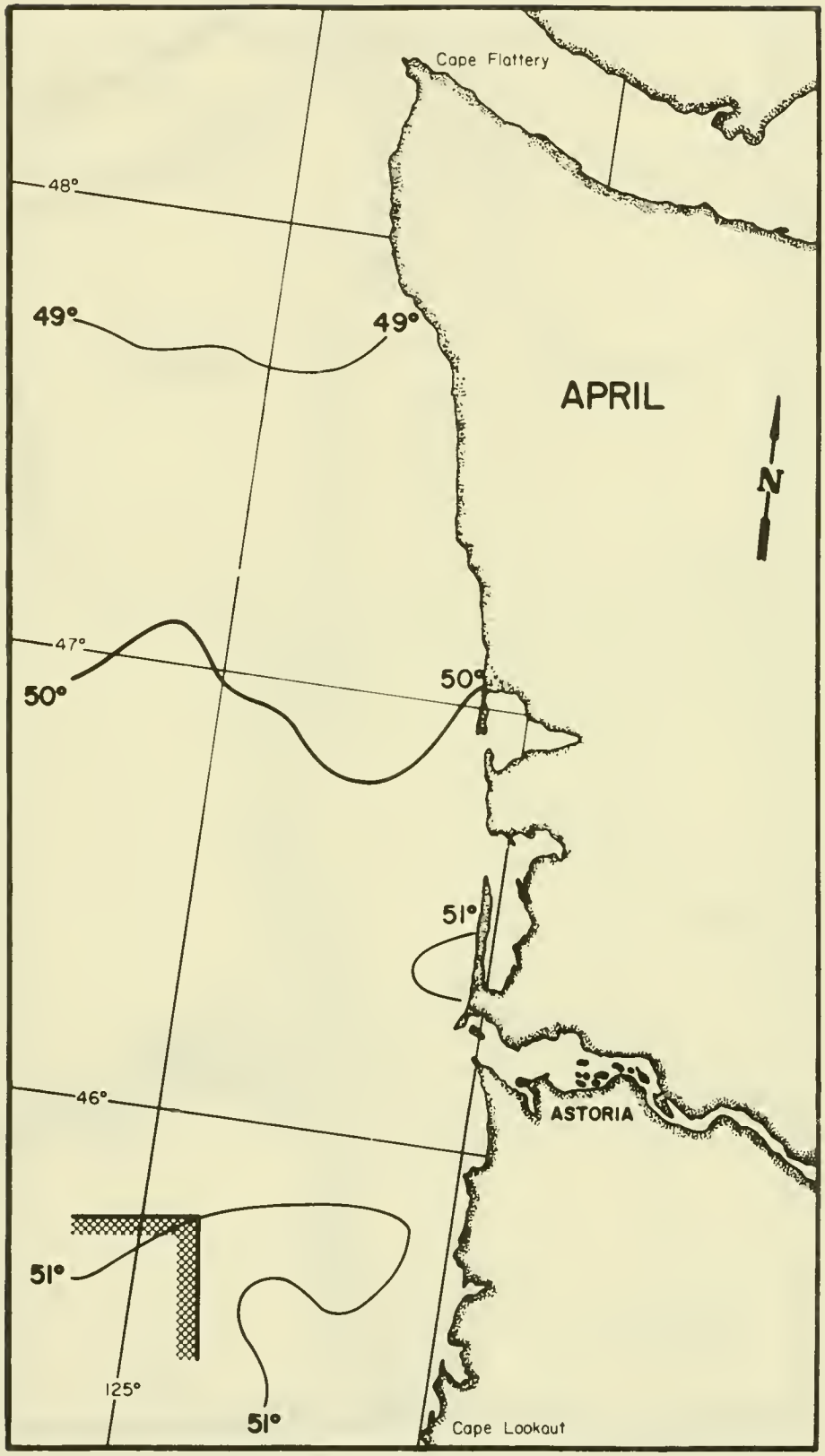



Figure 35. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

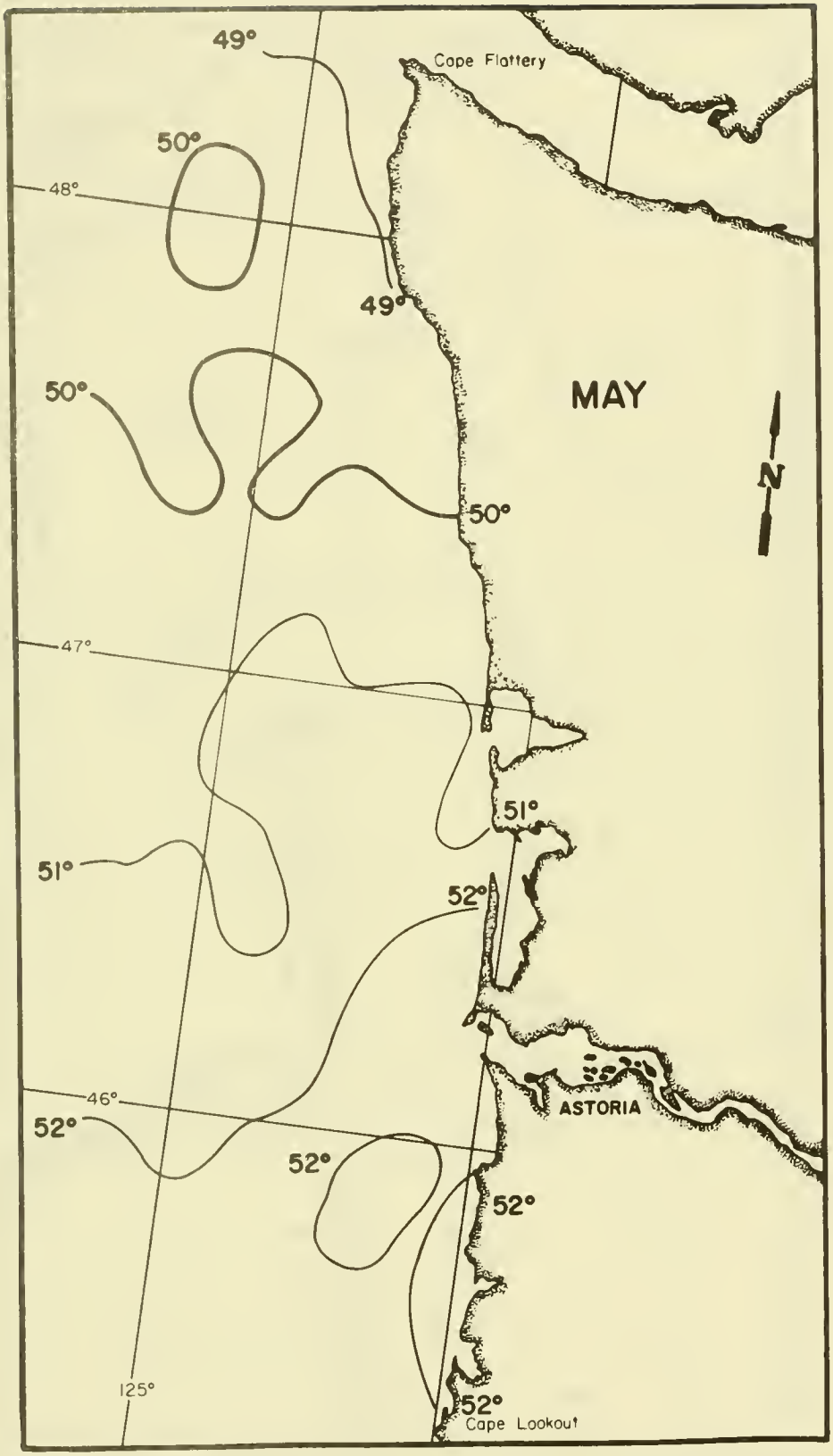



Figure 36. Five-year mean monthly distribution of sea surface temperature (°F.).

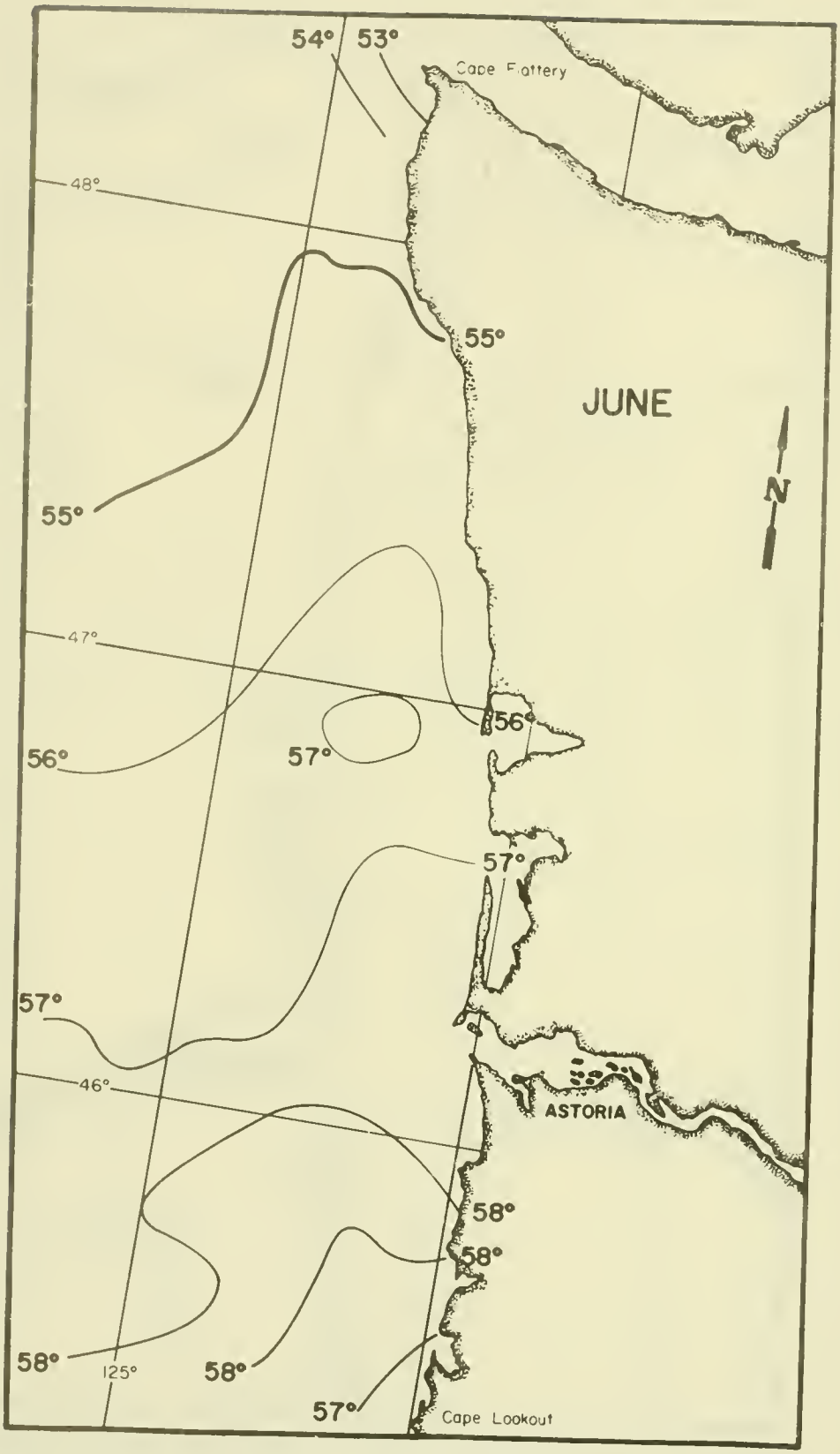



Figure 37. Five-year mean monthly distribution of sea surface temperature (°F.).

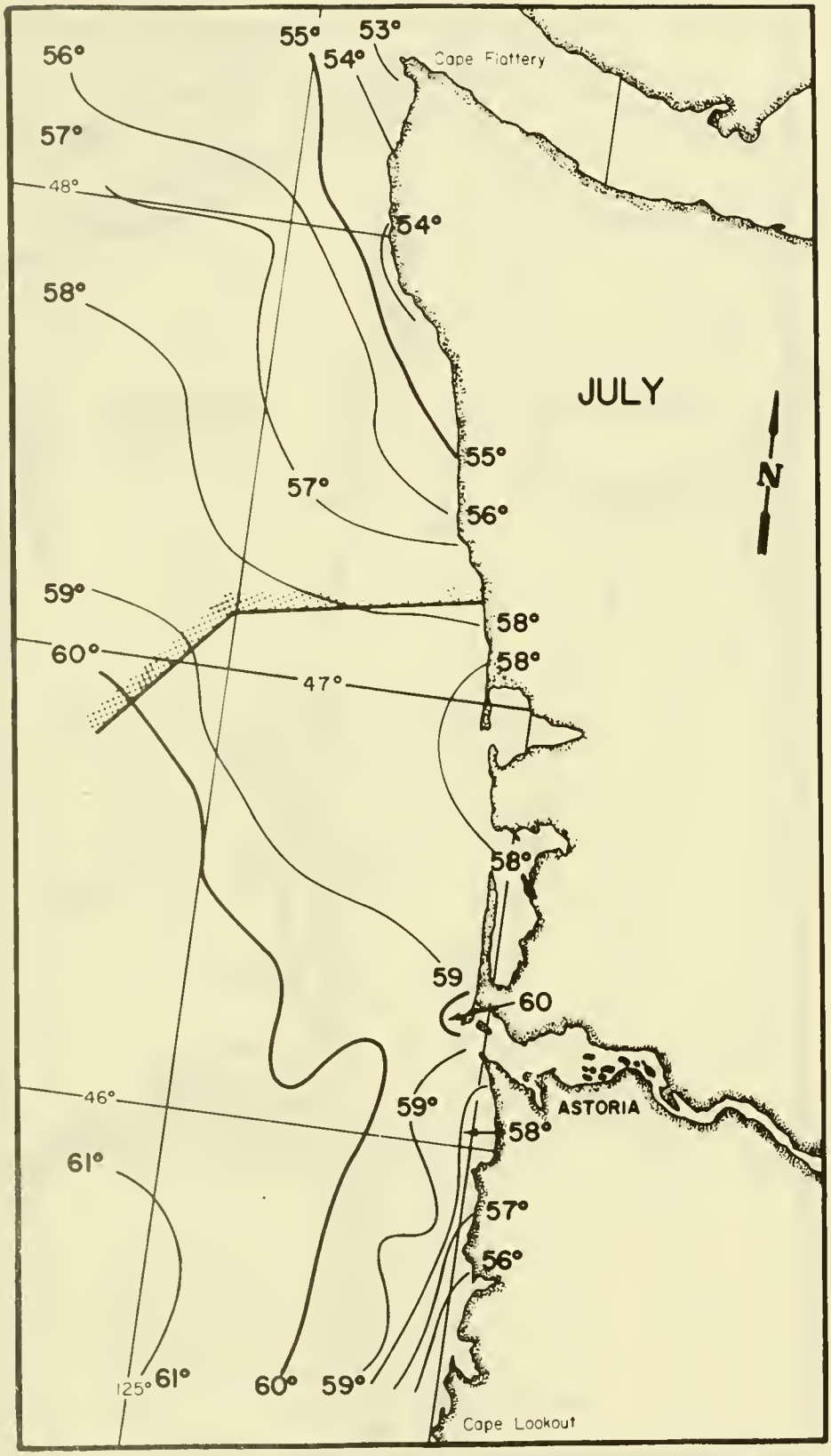



Figure 38. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

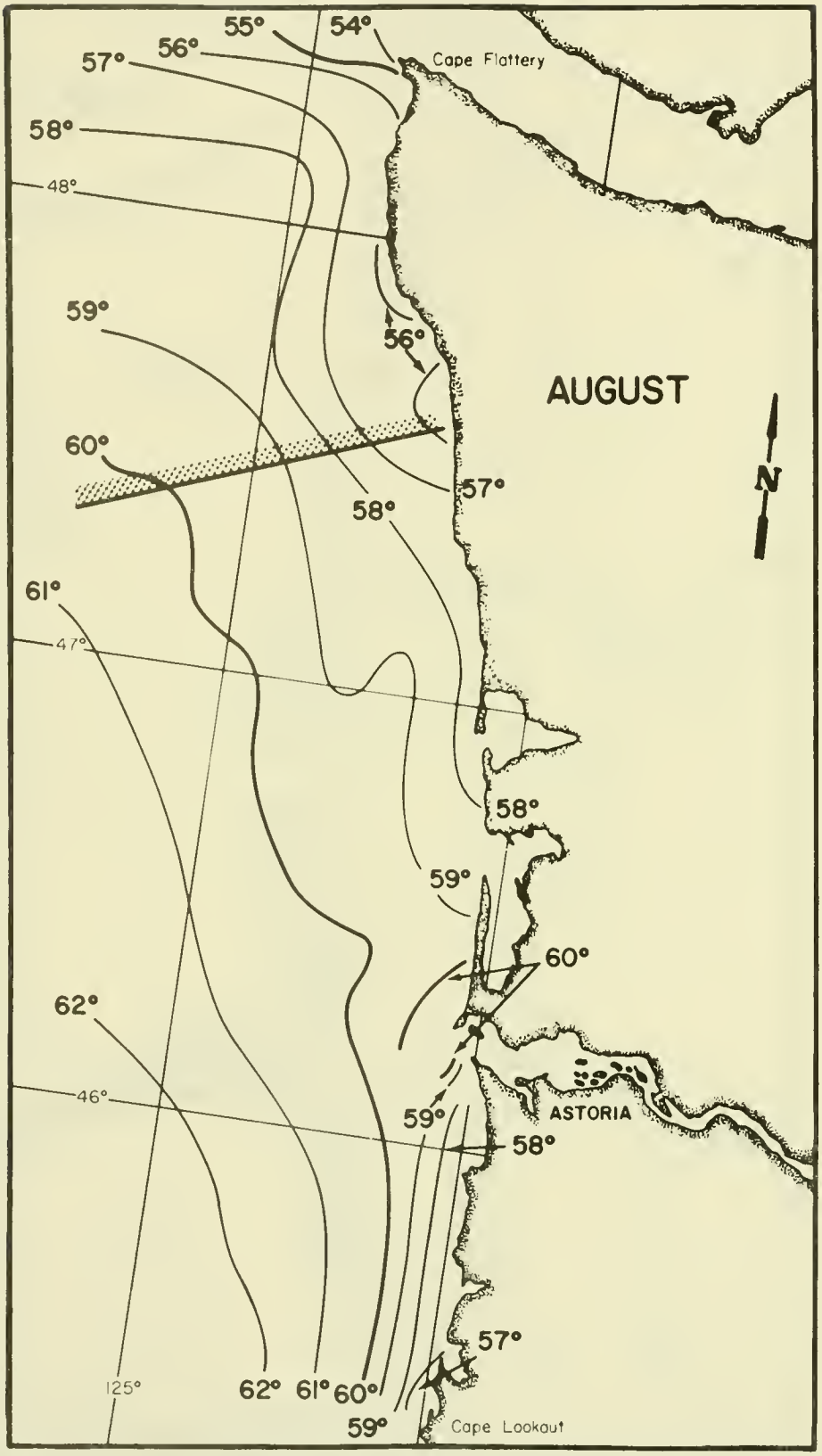



**Figure 39.** Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

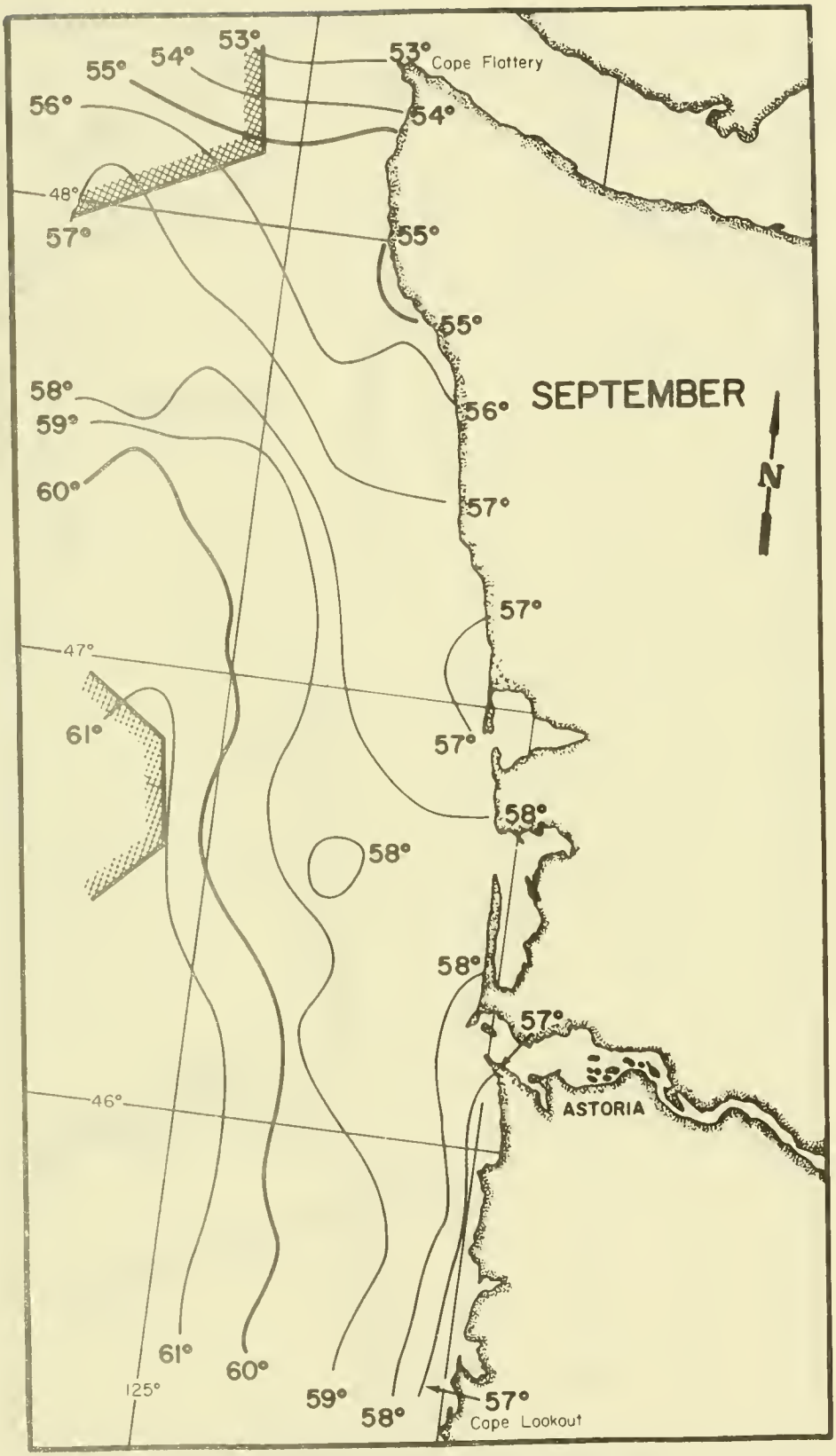



Figure 40. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

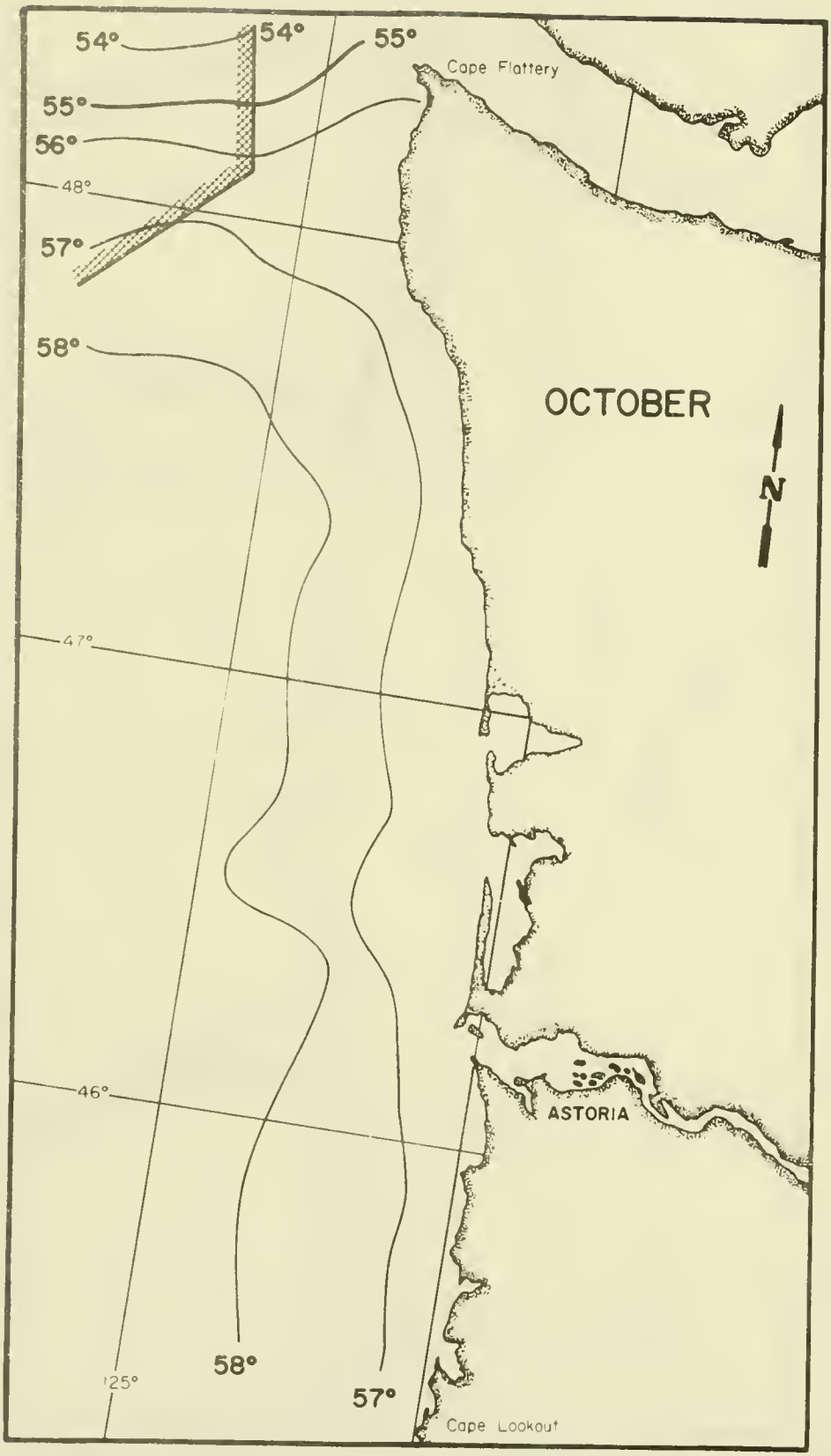



Figure 41. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

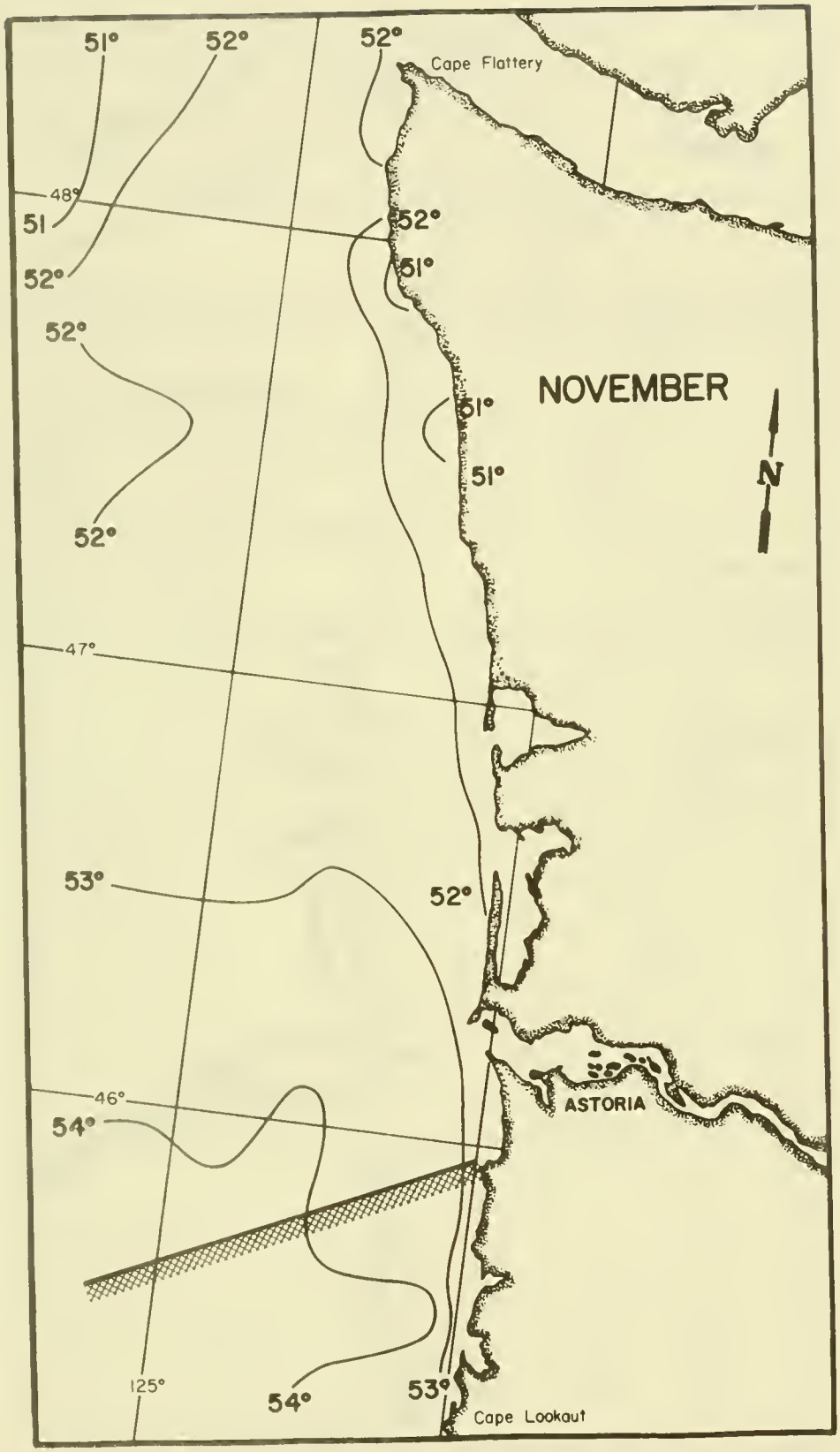



Figure 42. Five-year mean monthly distribution of sea surface temperature (°F.).

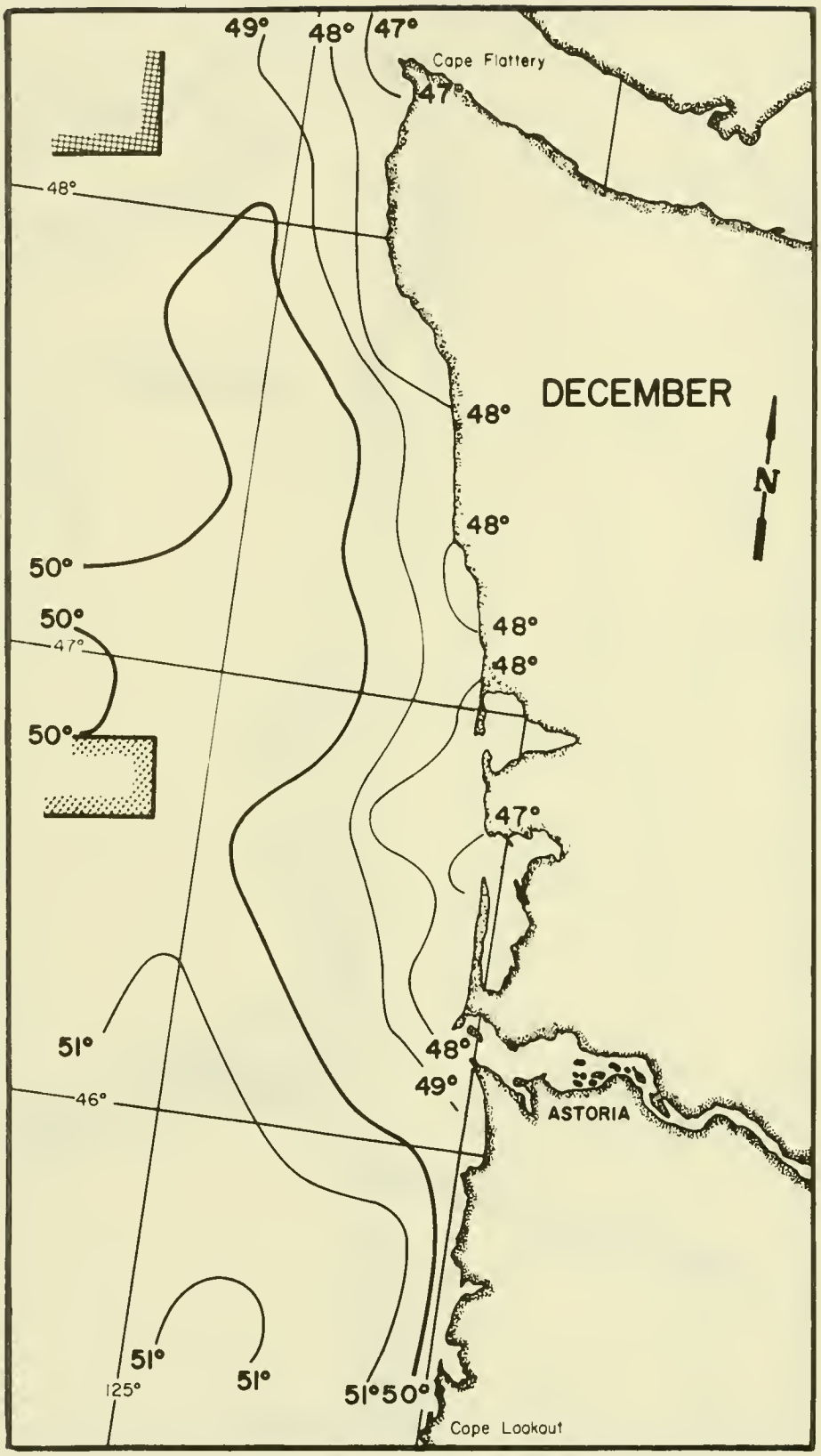



Figure 43. Five-year mean monthly distribution of sea surface temperature (°F.). Shaded side of heavy lines indicates that less than five monthly surveys were made in adjacent areas due to operational interferences.

# APPENDIX A

## Sea Surface Temperature Data

Monthly isotherm charts for August 1963–July 1968. Charts arranged chronologically in geographical groups, southern area first, followed by the central and northern areas.

Legend

Temperatures in °F

Inset numbers (such as 1–11–67) indicate date of flight (day-month-year).

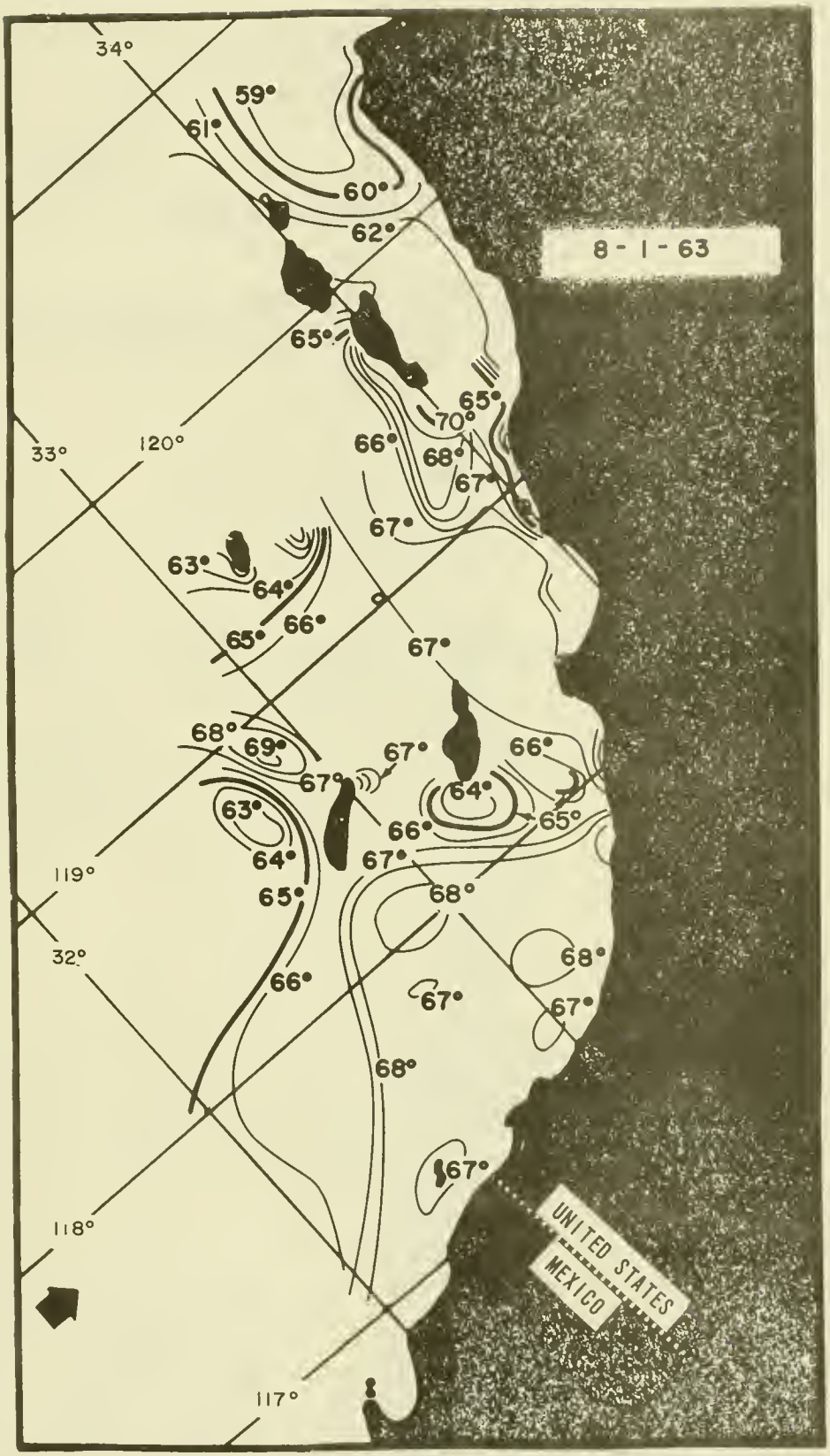
/////// indicates limit of fog

---------- indicates interpolated estimate of isotherm position

< indicates lower temperature

> indicates higher temperature

For geographical location of survey areas and flight tracks see figures 3, 4, and 5.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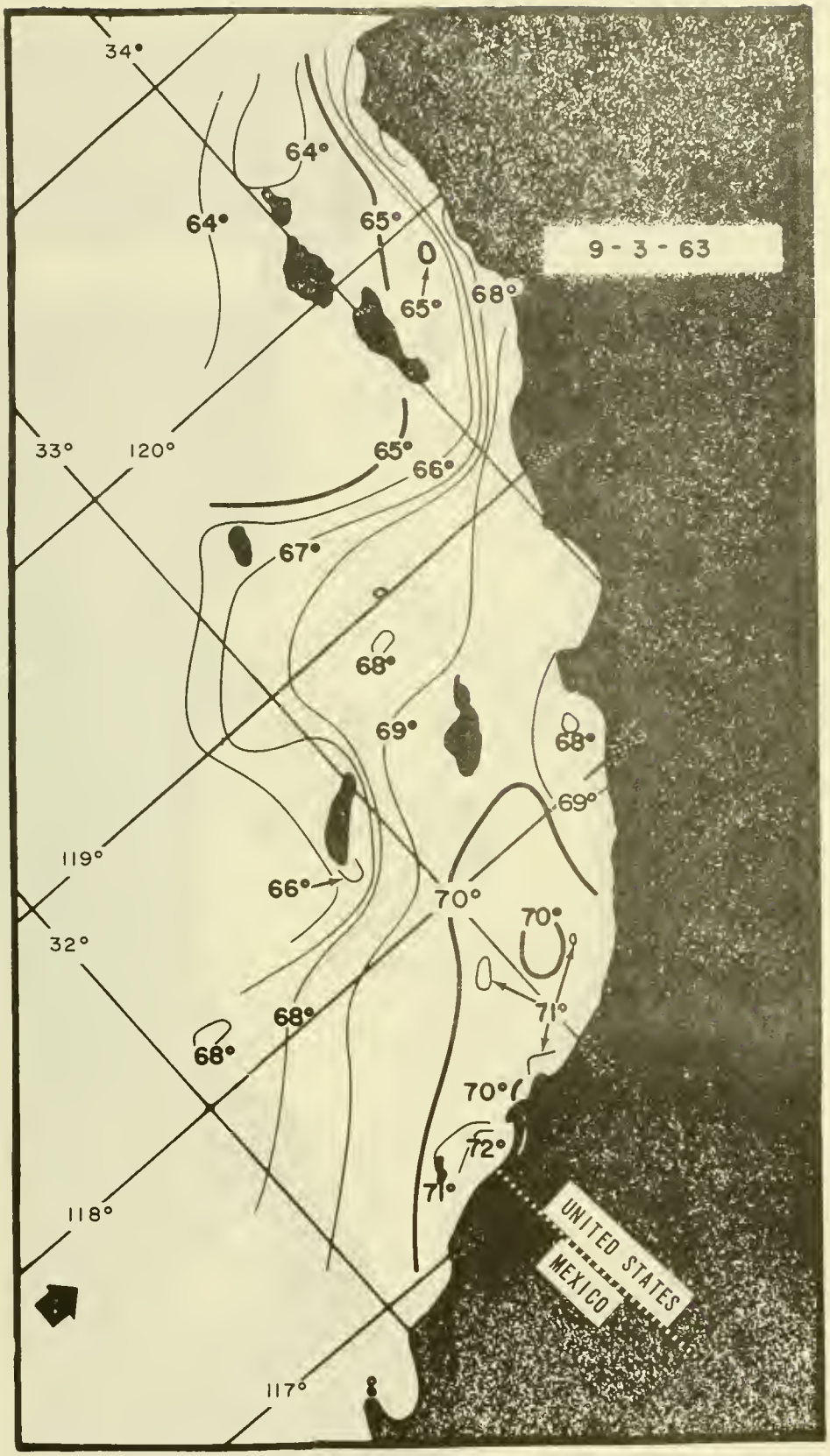
34°
59°
61°
60°
62°
65°
65°
70°
66°
68°
67°
67°
33°
120°
63°
64°
65°
66°
67°
68°
69°
67°
67°
66°
64°
63°
66°
65°
64°
67°
119°
65°
68°
68°
32°
66°
67°
67°
68°
67°
118°
UNITED STATES
MEXICO
117°


9 - 3 - 63
34°
64°
64°
65°
65°
68°
33°
120°
65°
66°
67°
68°
69°
68°
69°
119°
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70°
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71°
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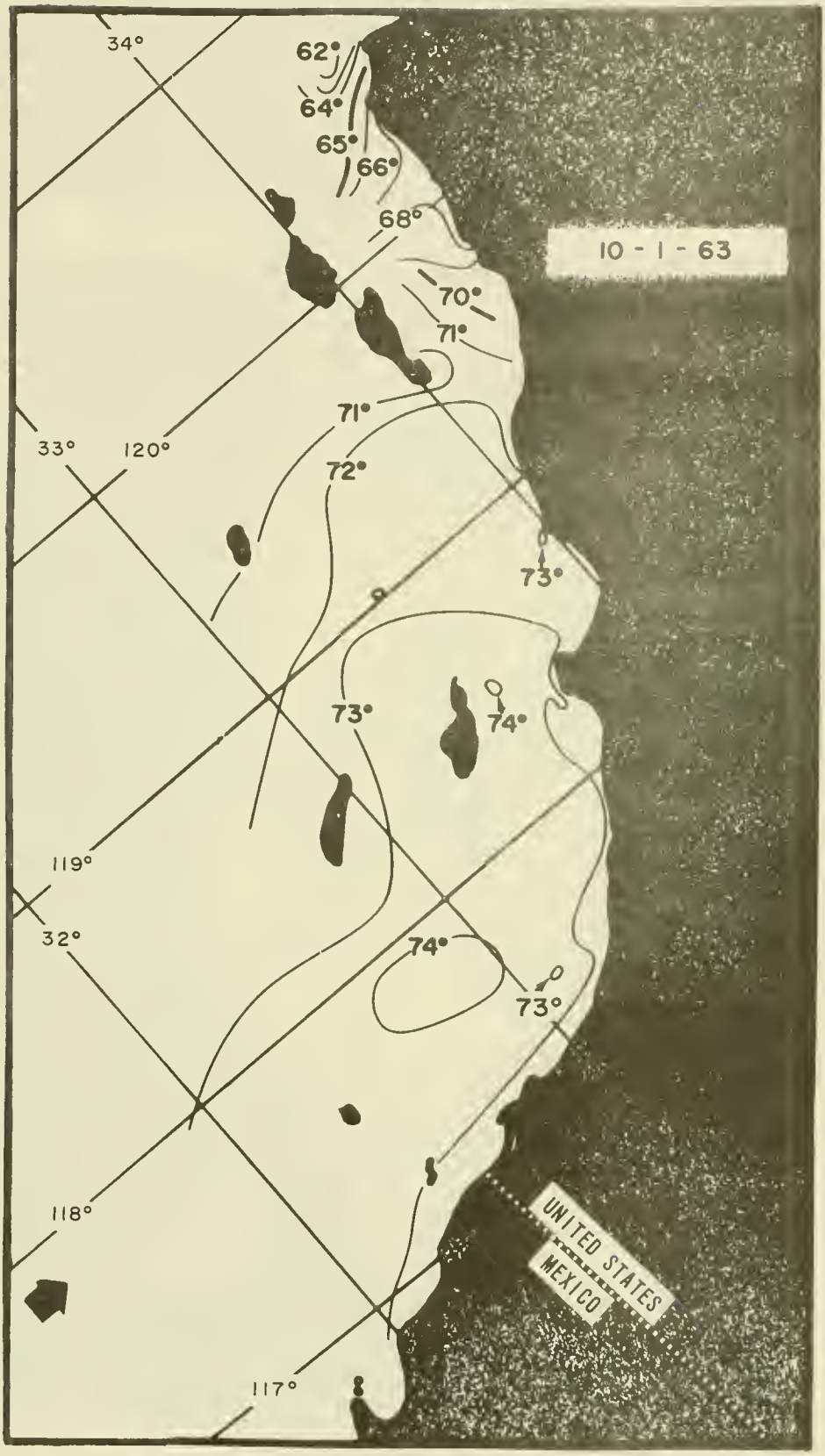
70°
72°
71°
118°
UNITED STATES
MEXICO
117°


34°
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64°
65°
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10 - 1 - 63
70°
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71°
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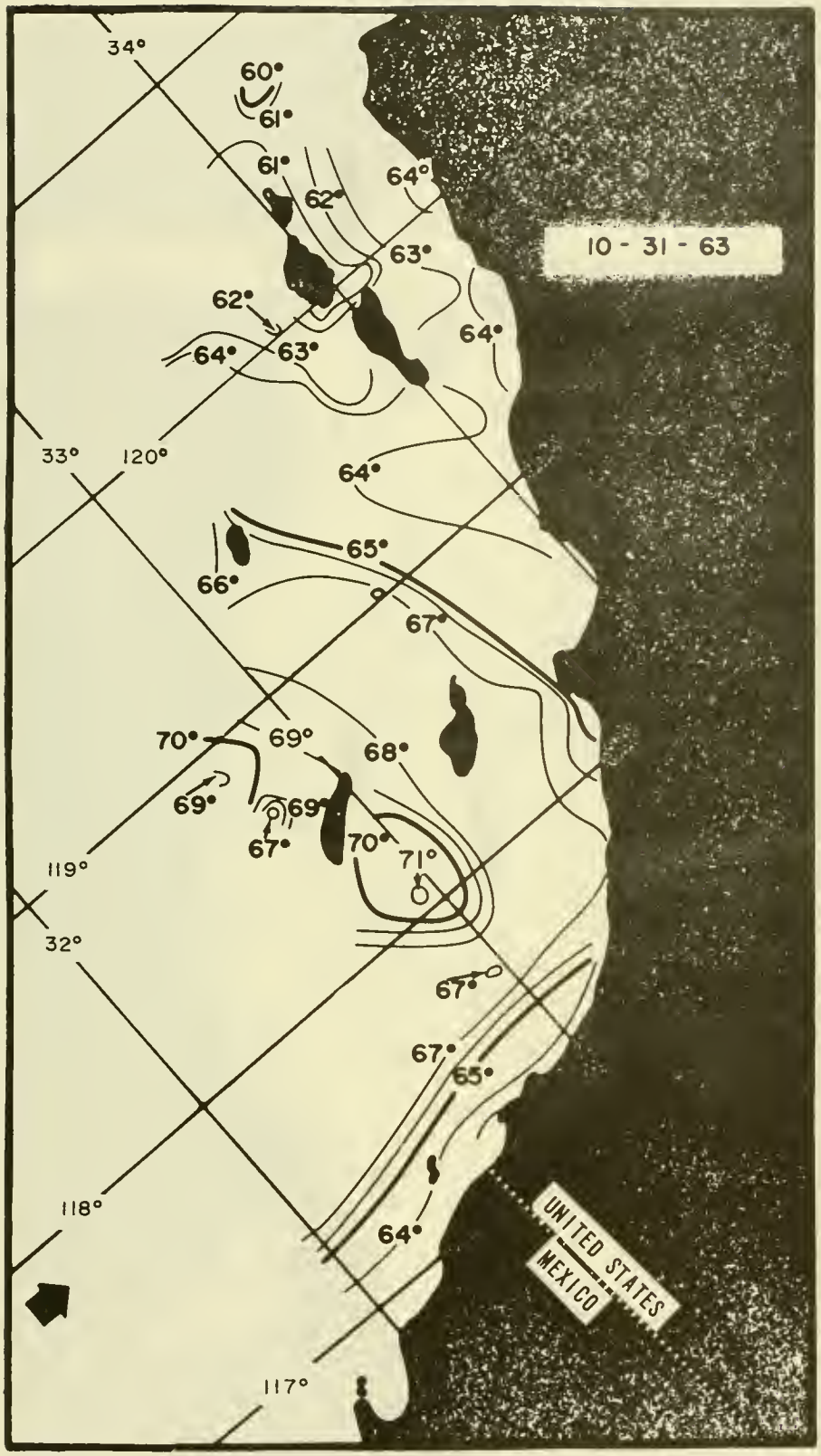
74°
119°
32°
74°
73°
118°
UNITED STATES
MEXICO
117°


34°
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62°
64°
63°
10 - 31 - 63
62°
64°
63°
64°
33°
120°
64°
65°
66°
67°
70°
69°
68°
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69°
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71°
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32°
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64°
UNITED STATES
MEXICO
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34°
57°
57°
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12 - 4 - 63
33°
120°
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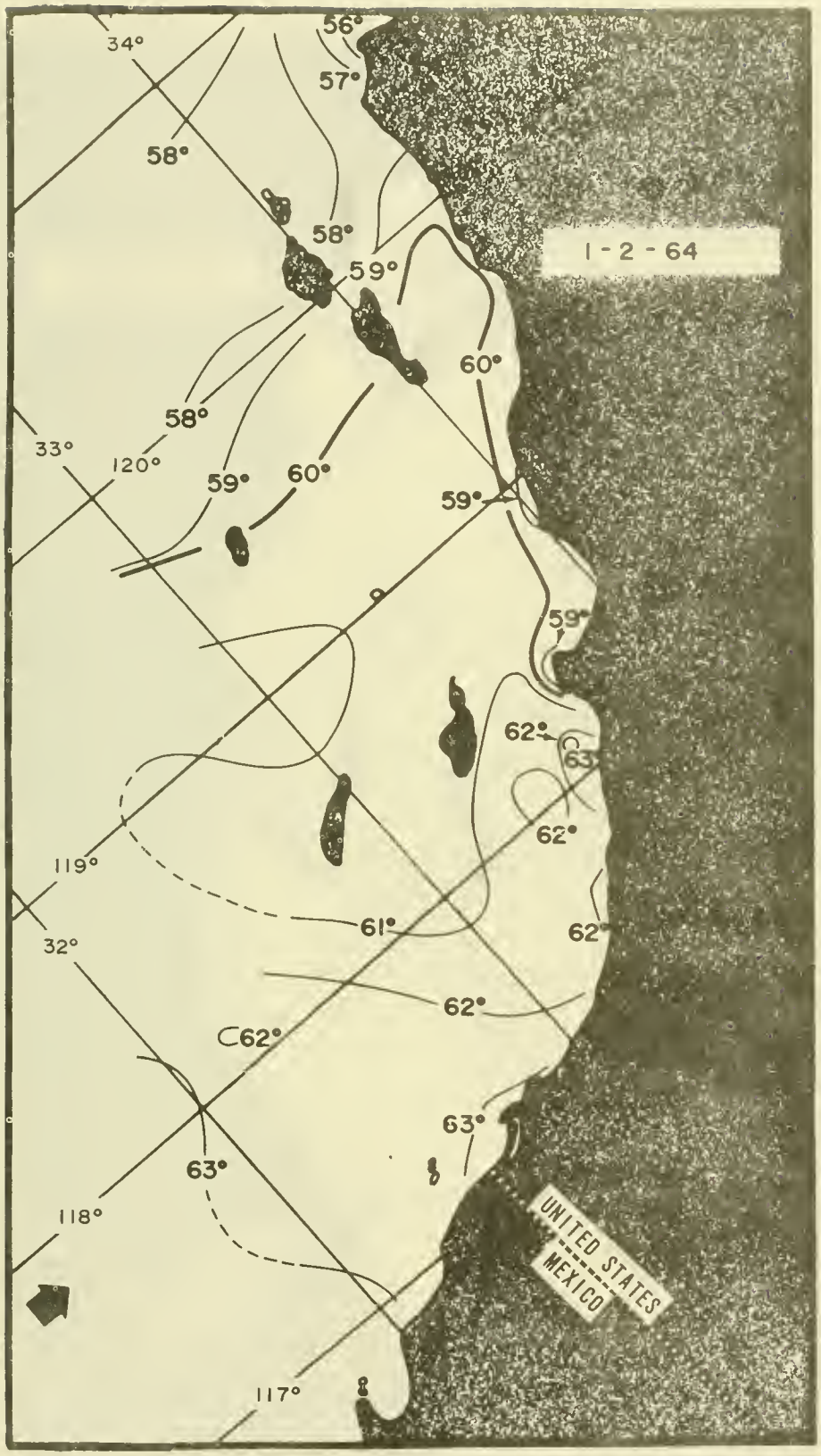
1 - 2 - 64
34°
56°
57°
58°
58°
59°
60°
58°
33°
120°
59°
60°
59°
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62°
63
62°
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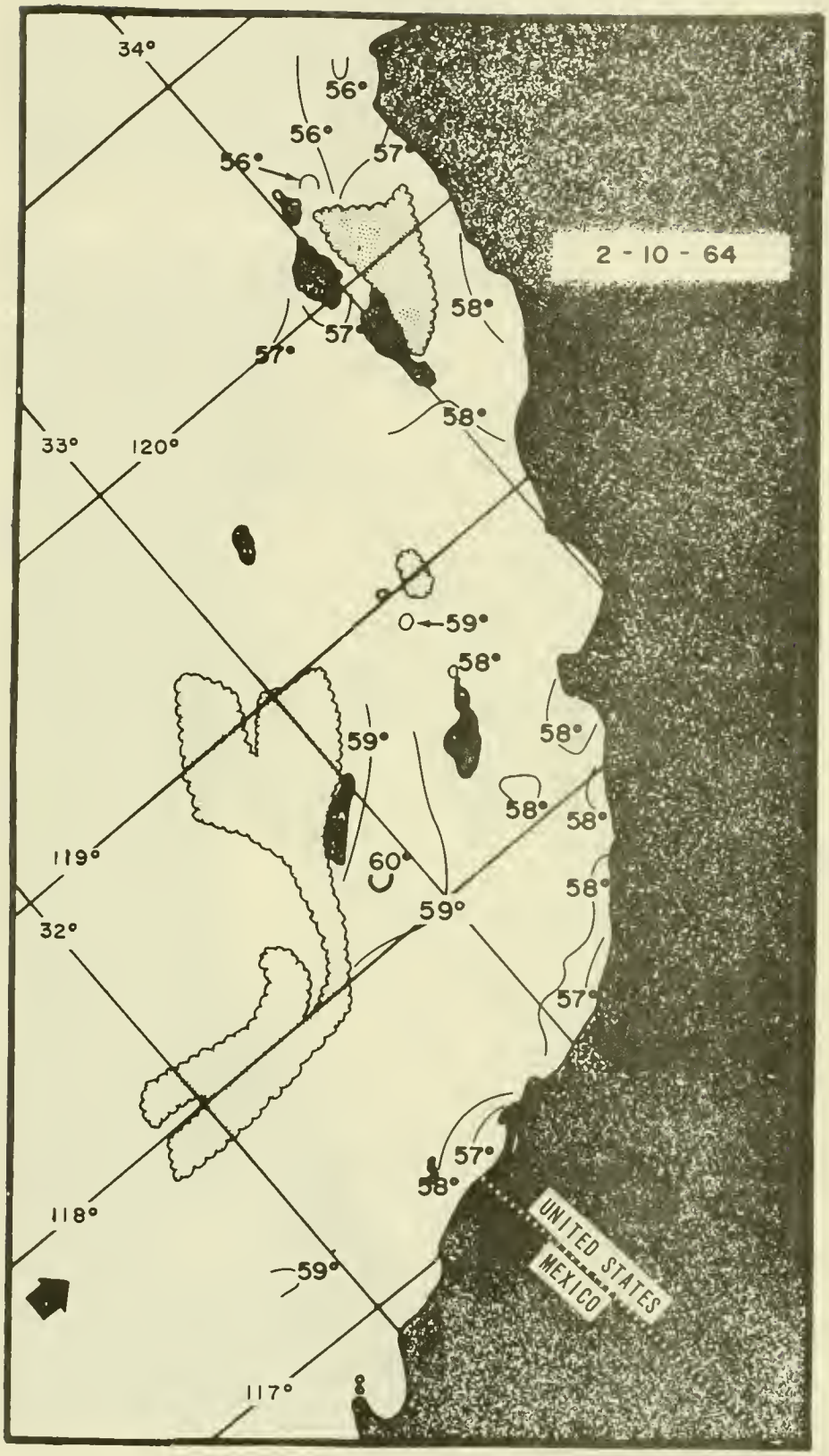
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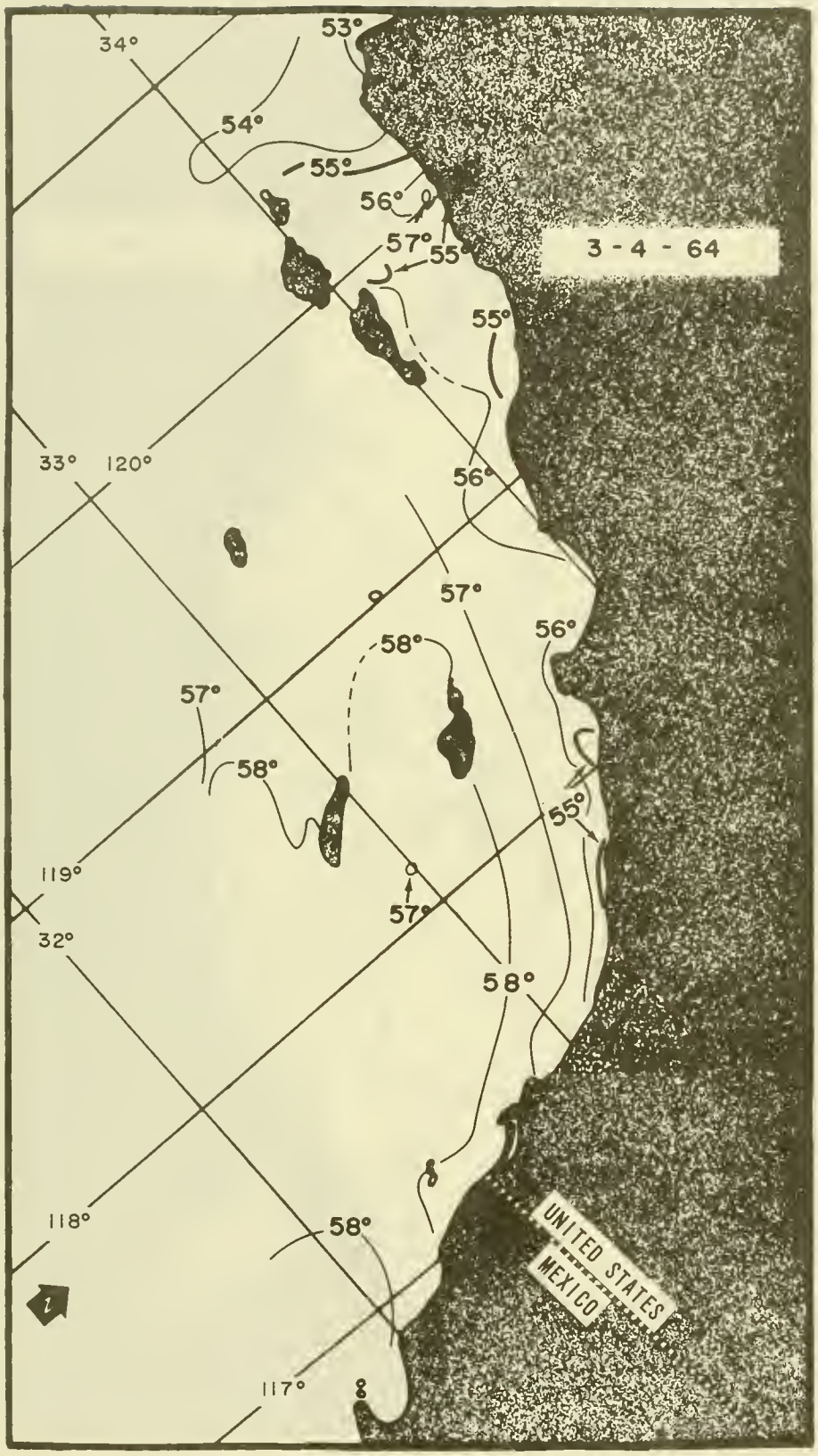
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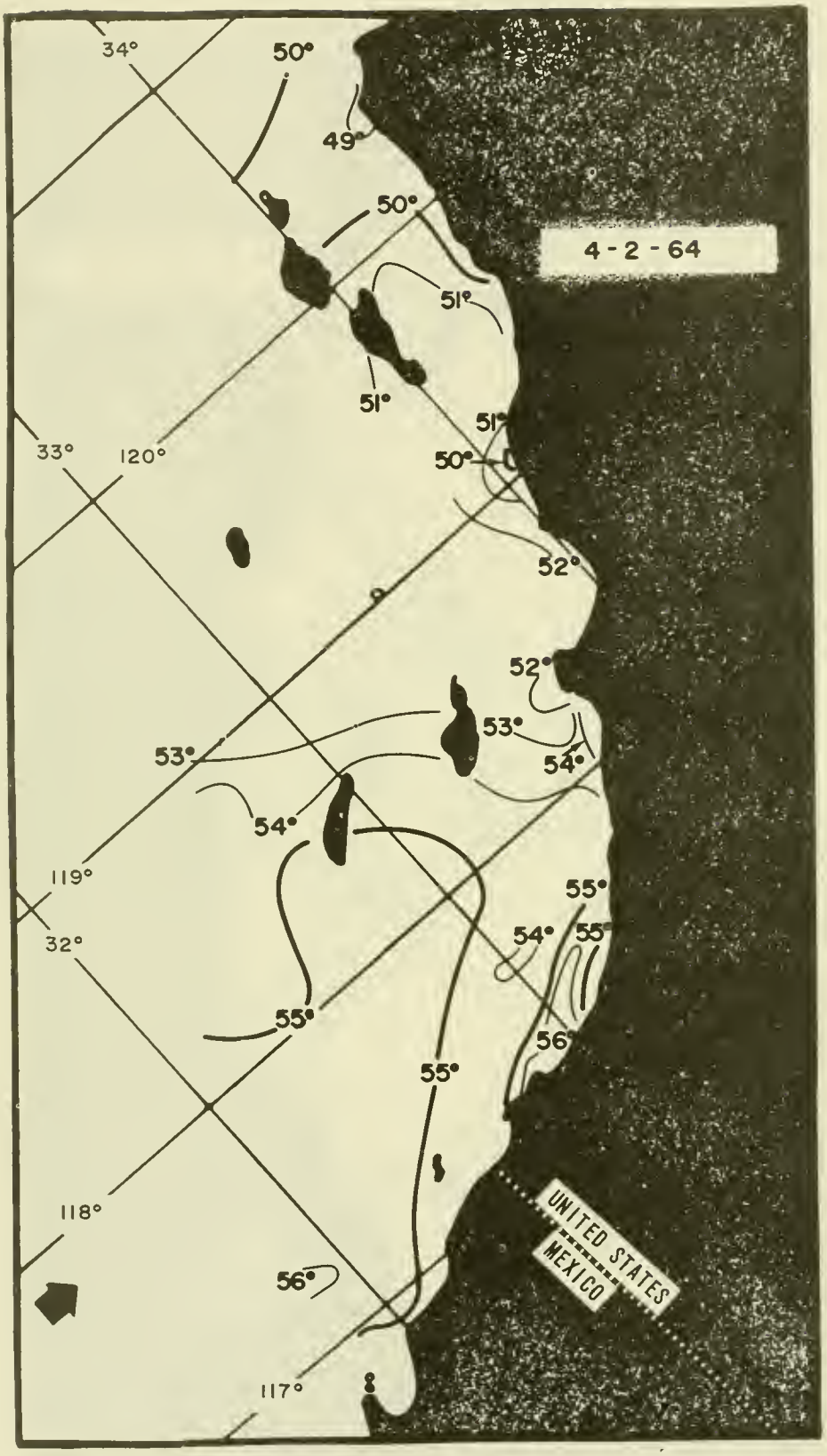
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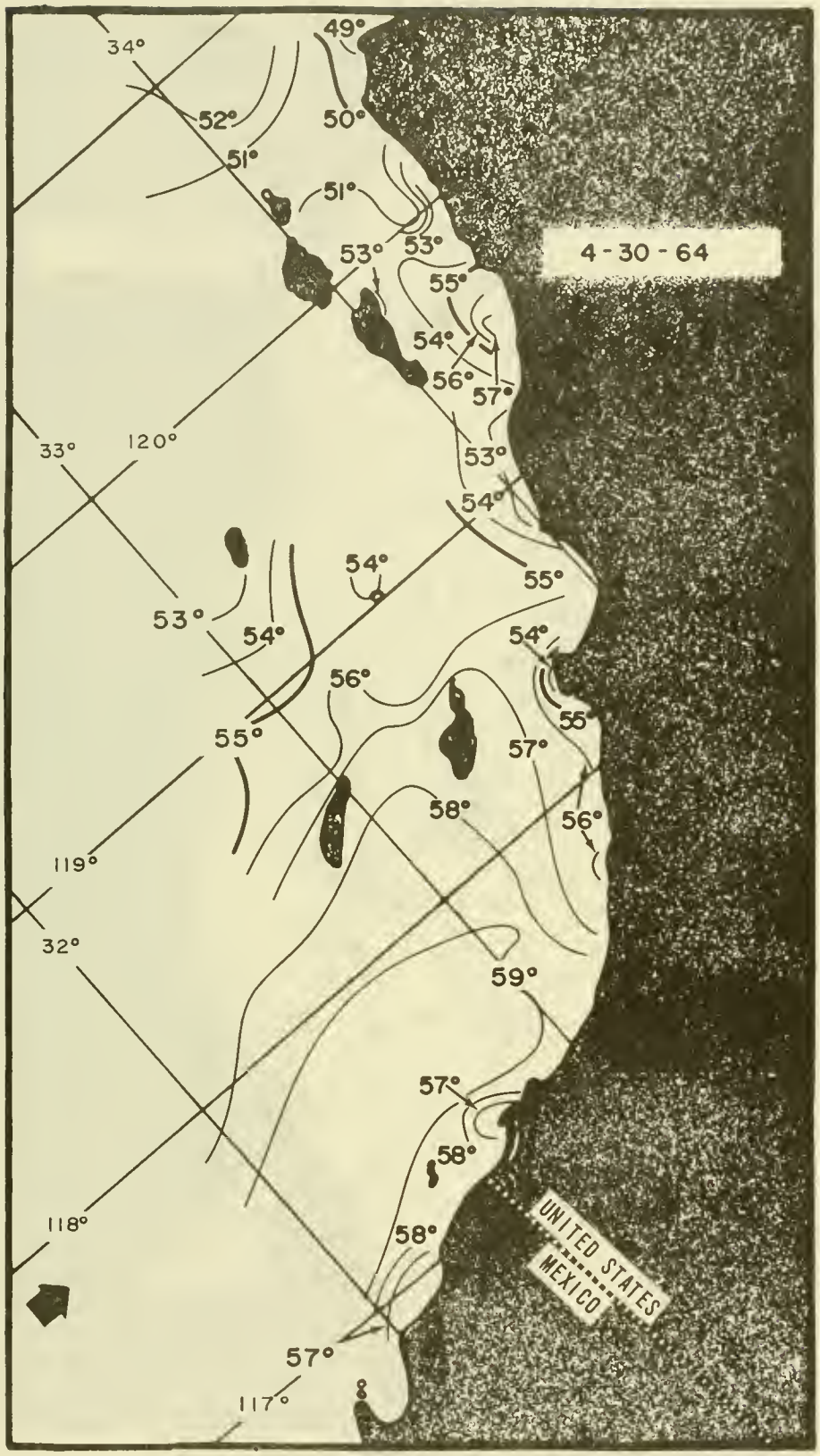
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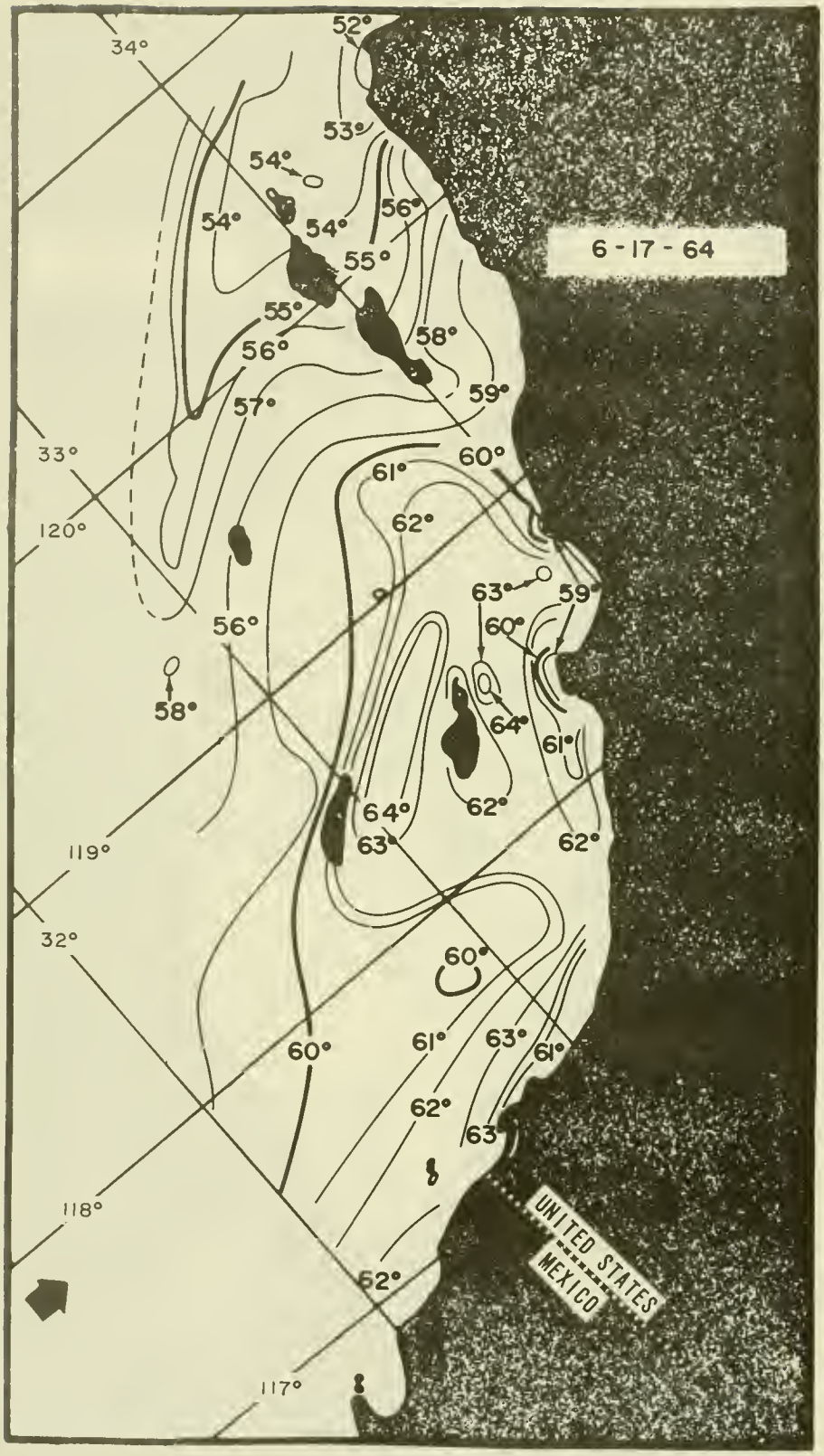
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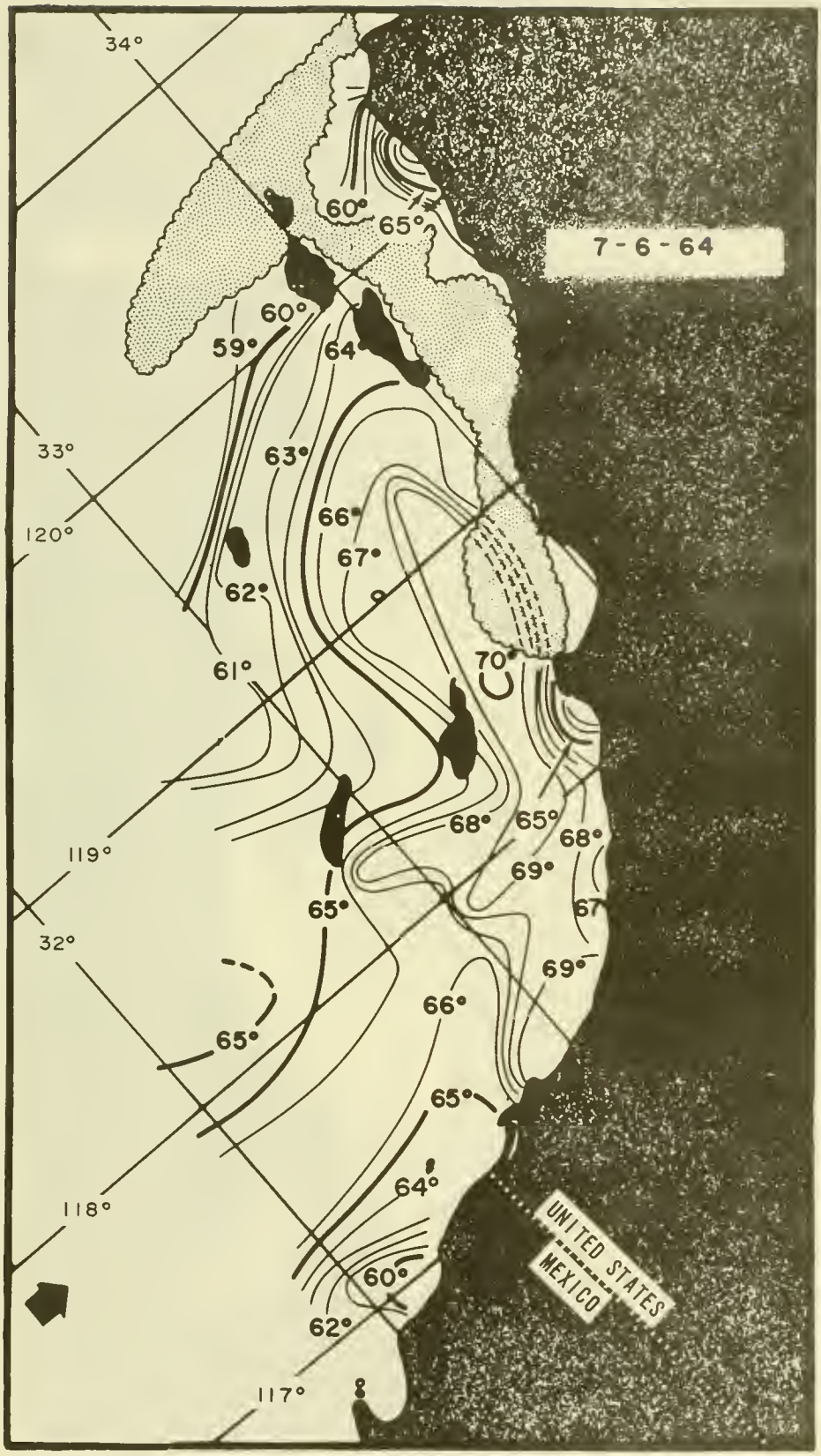
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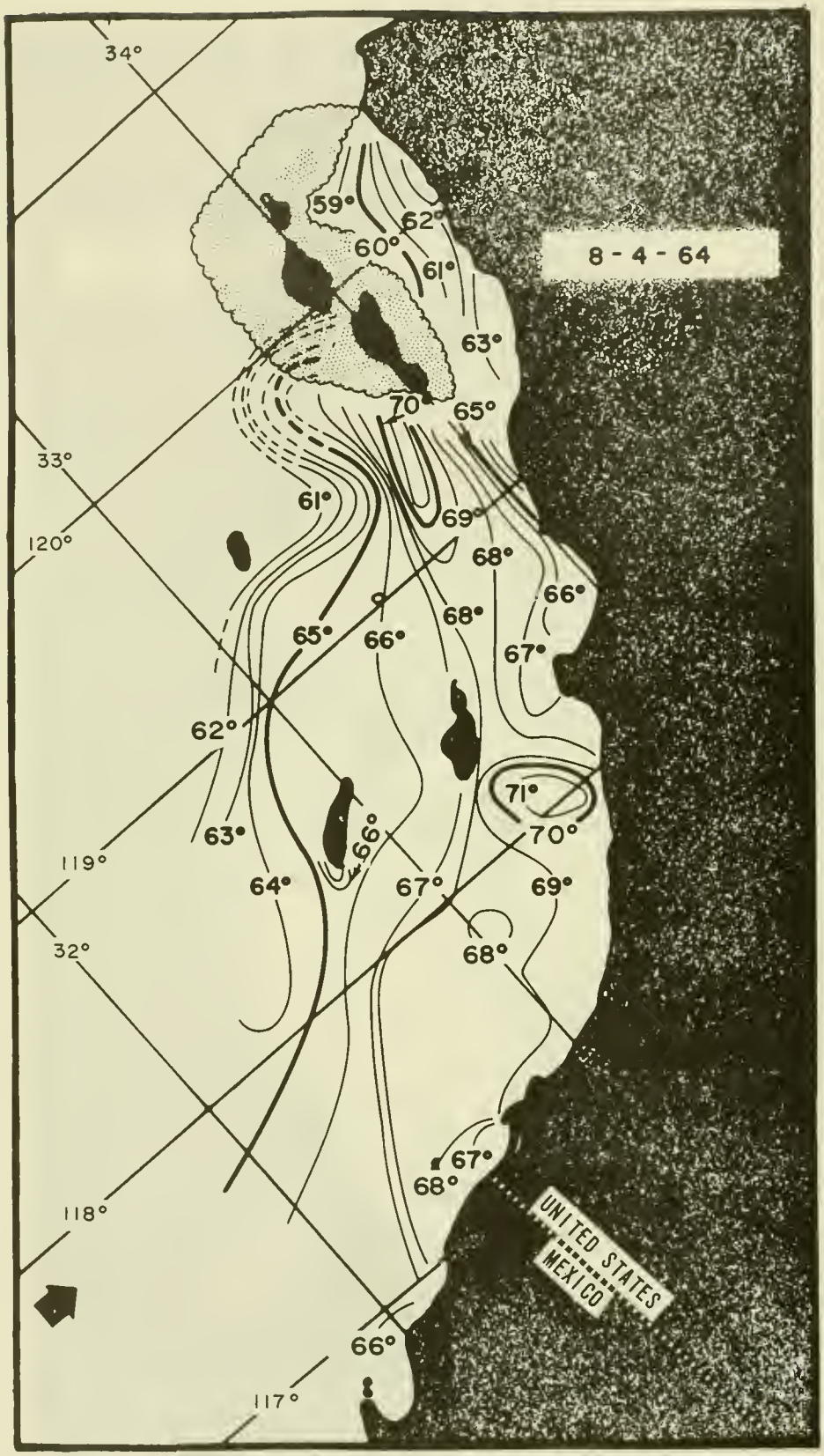
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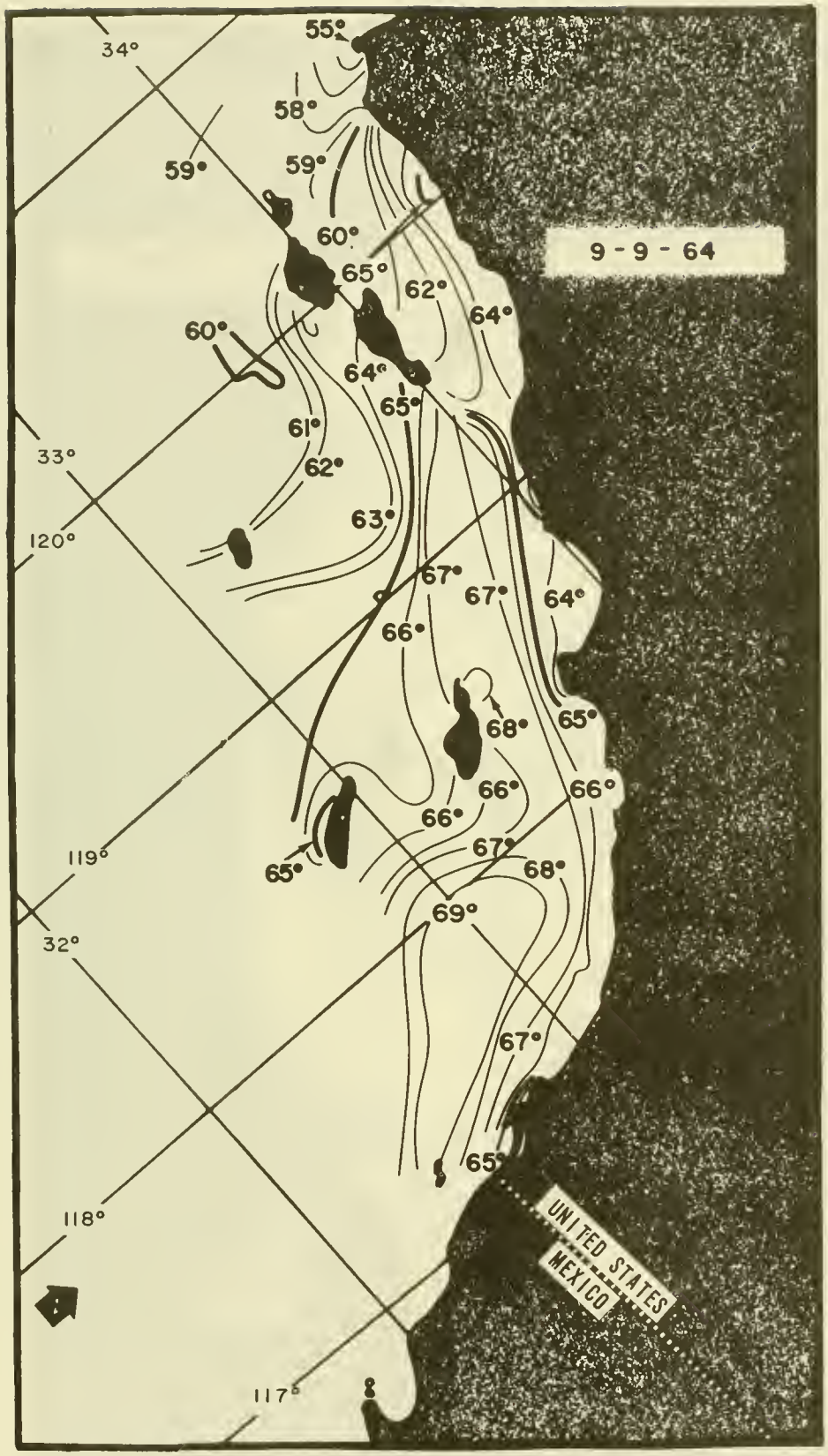
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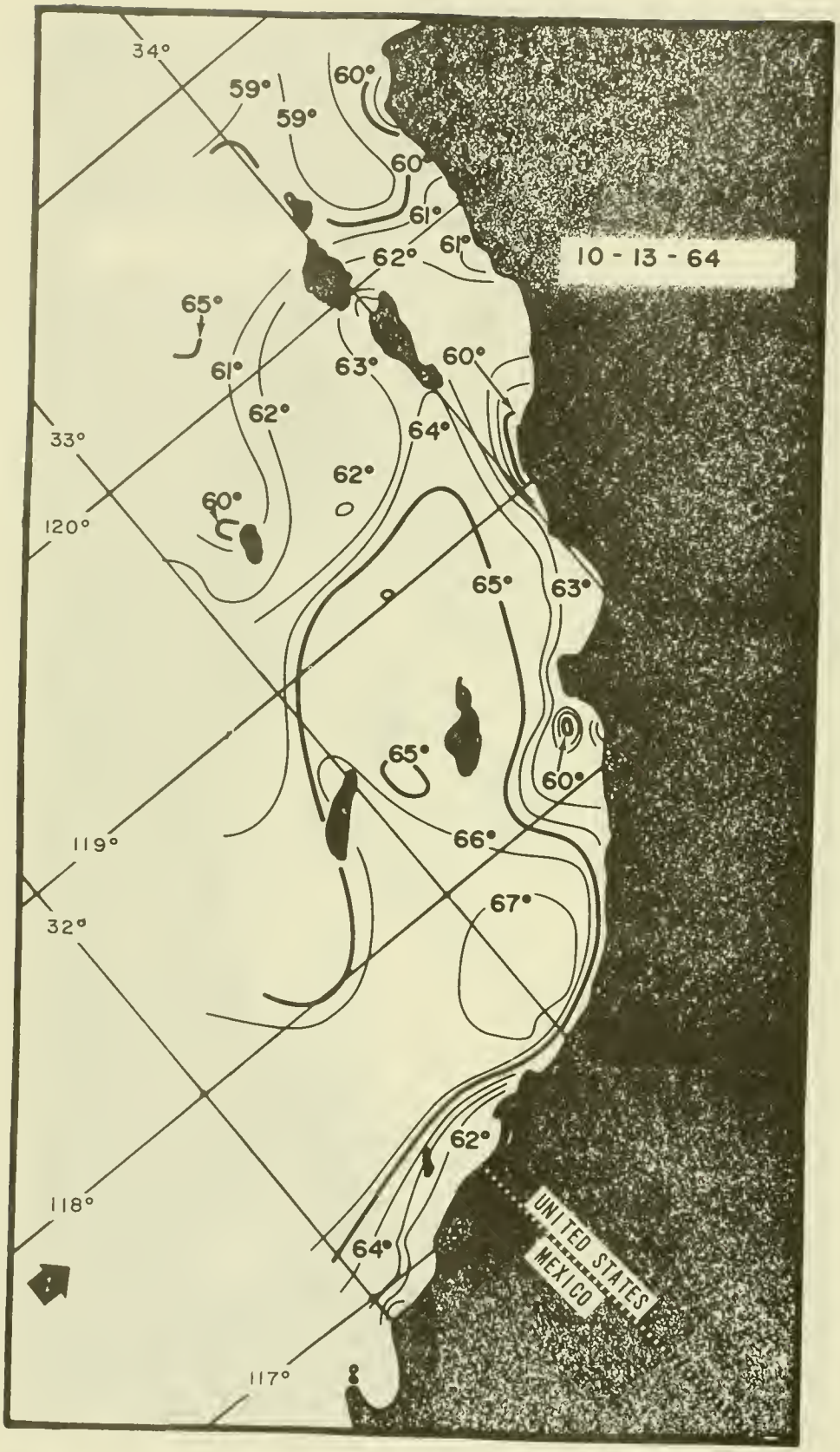
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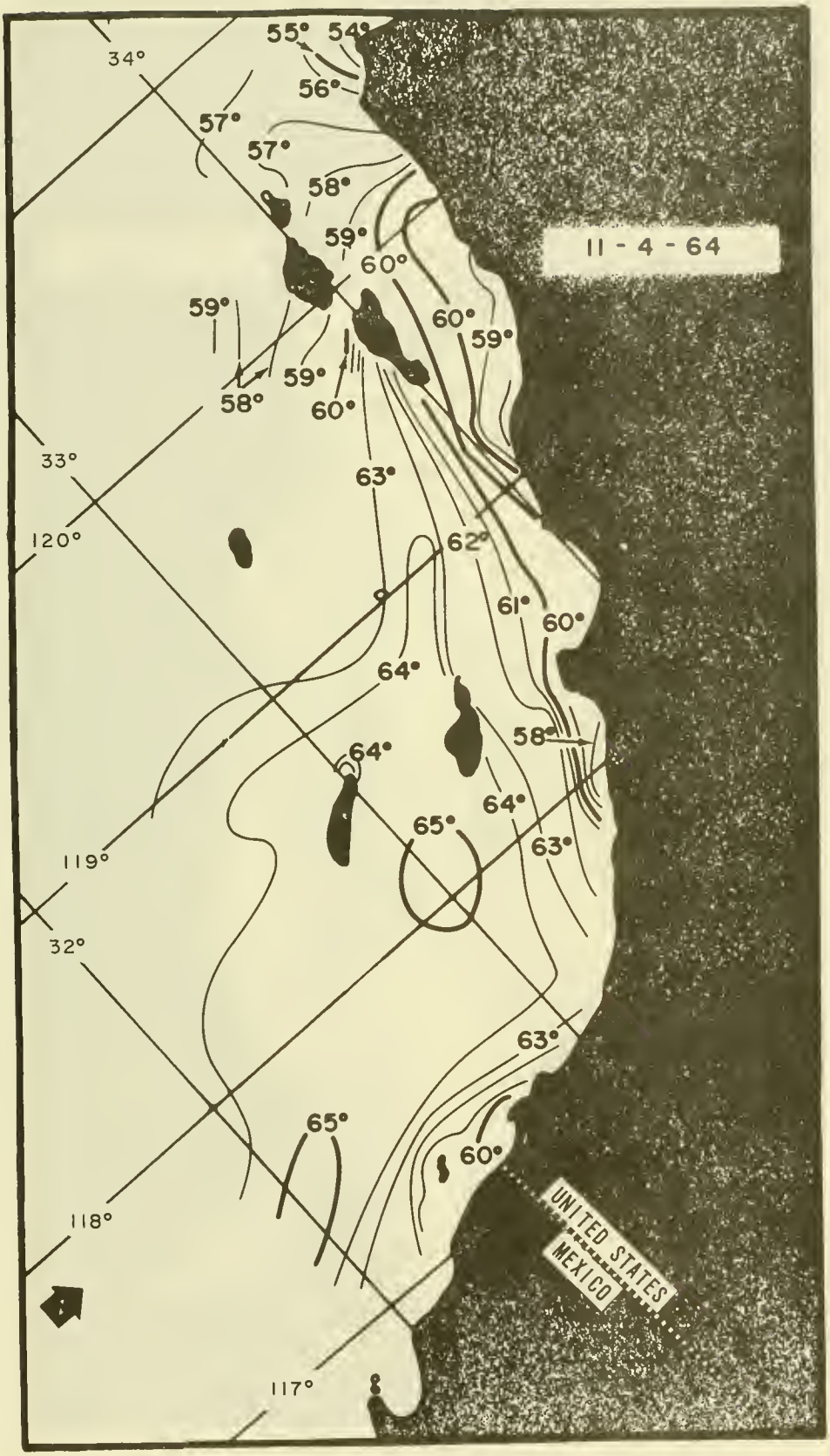
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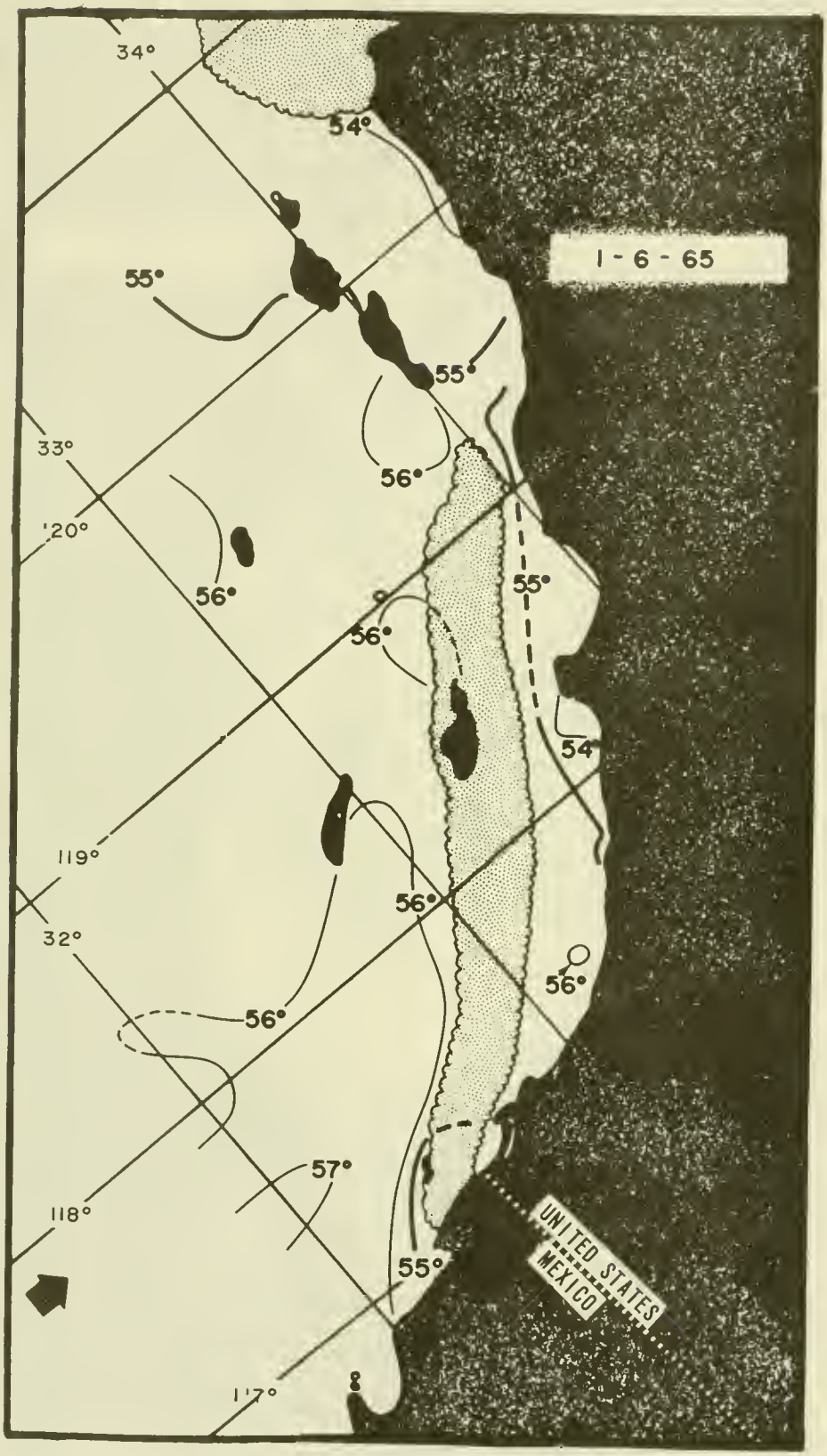
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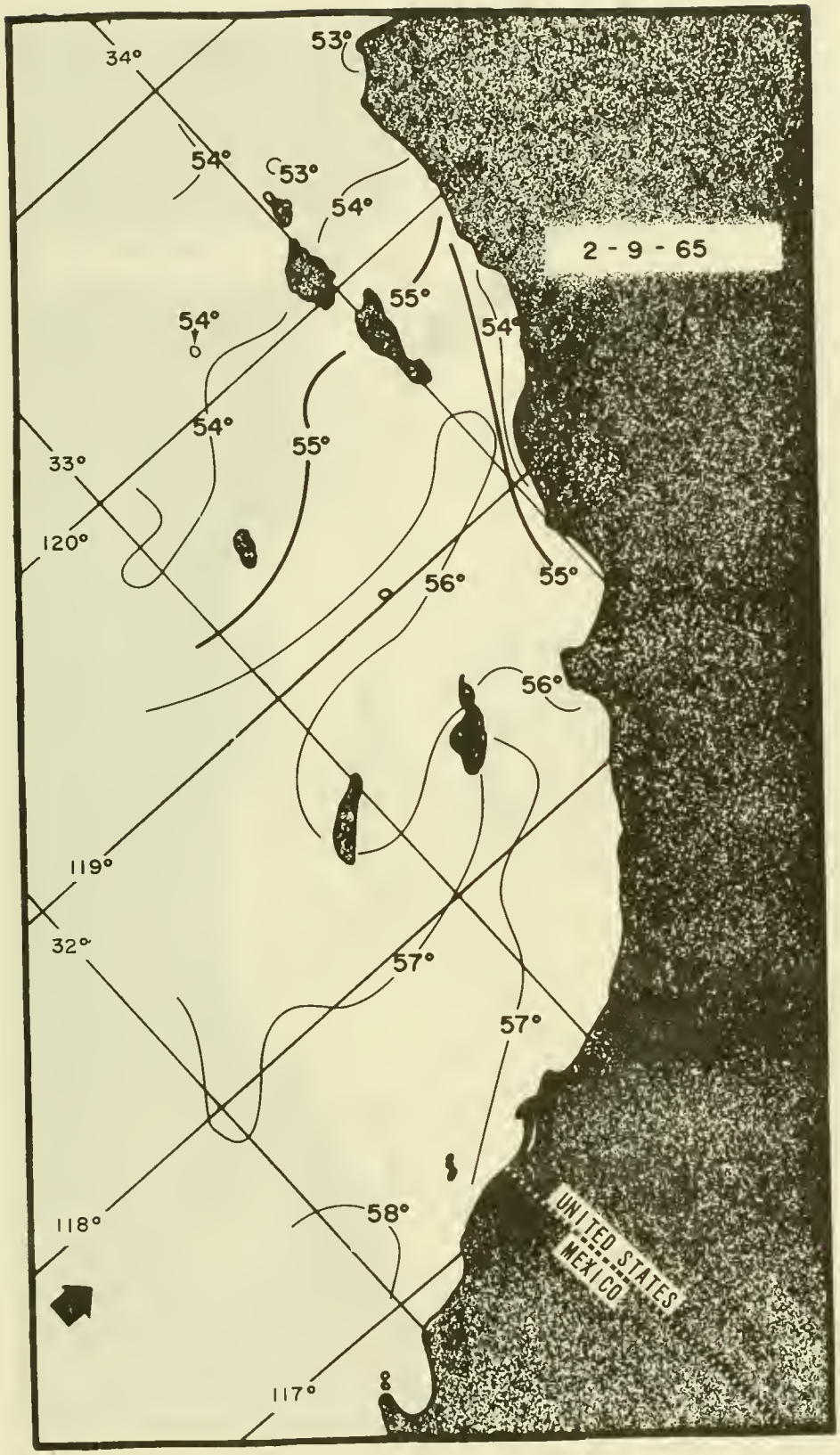
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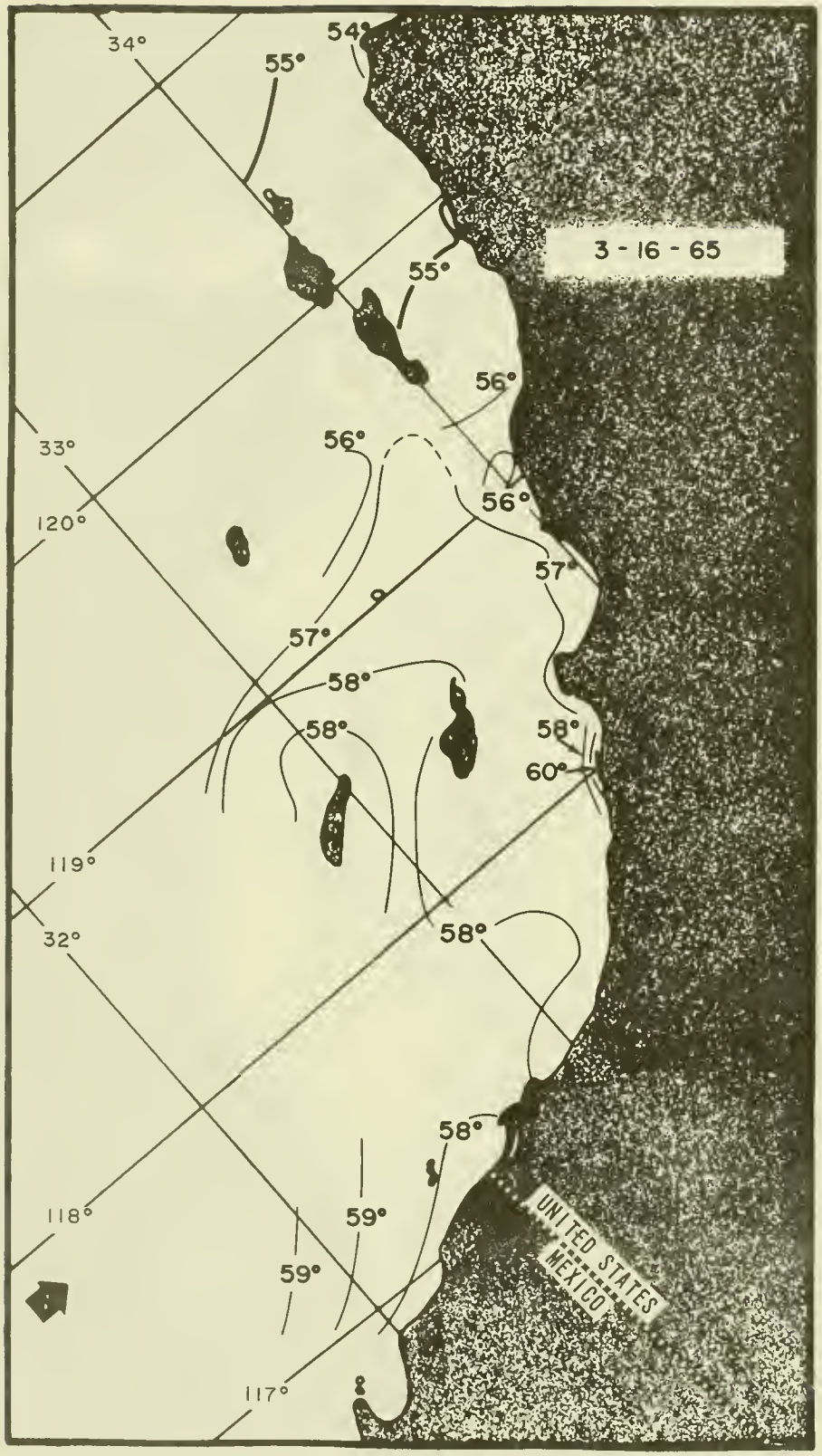
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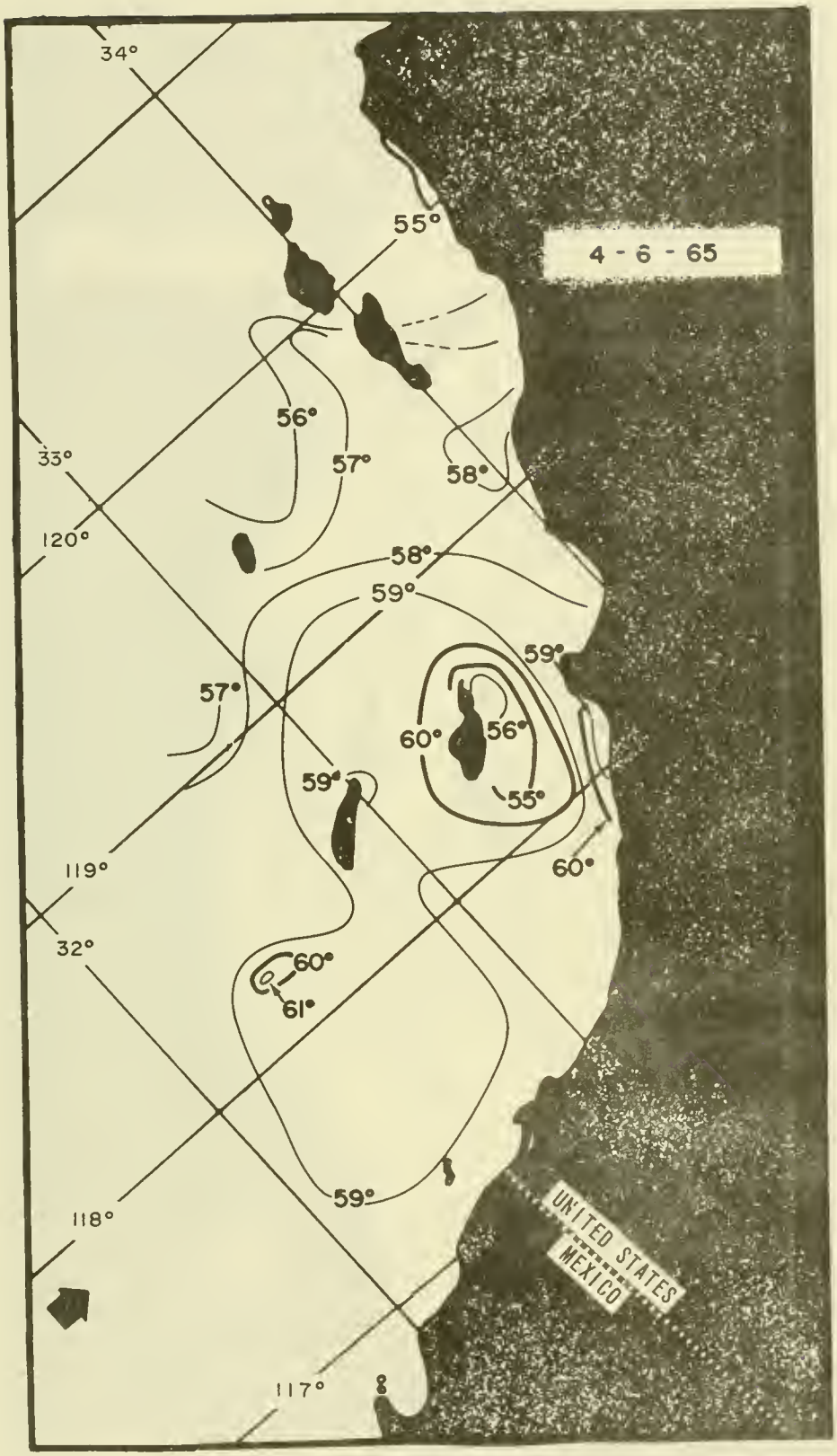
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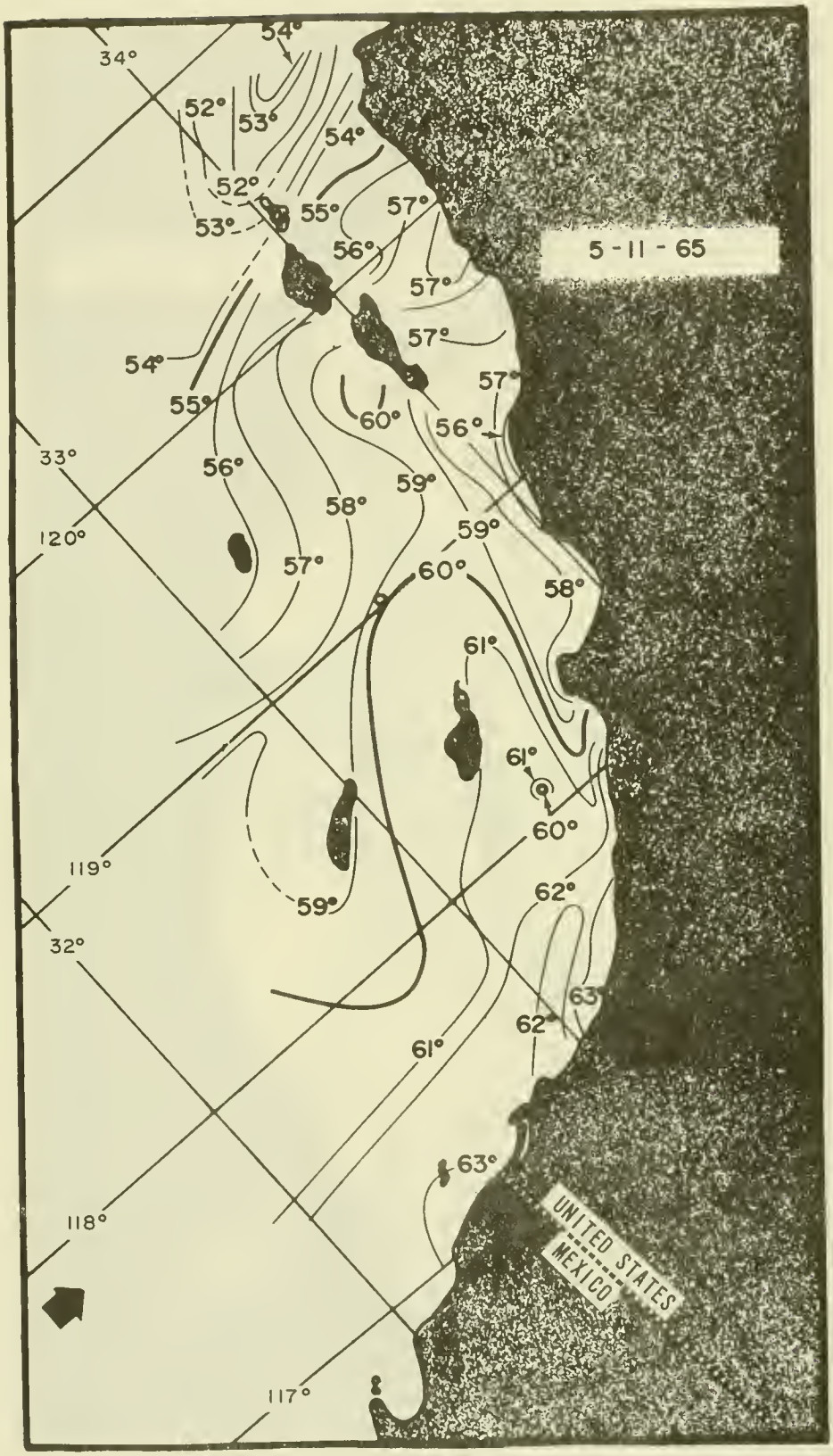
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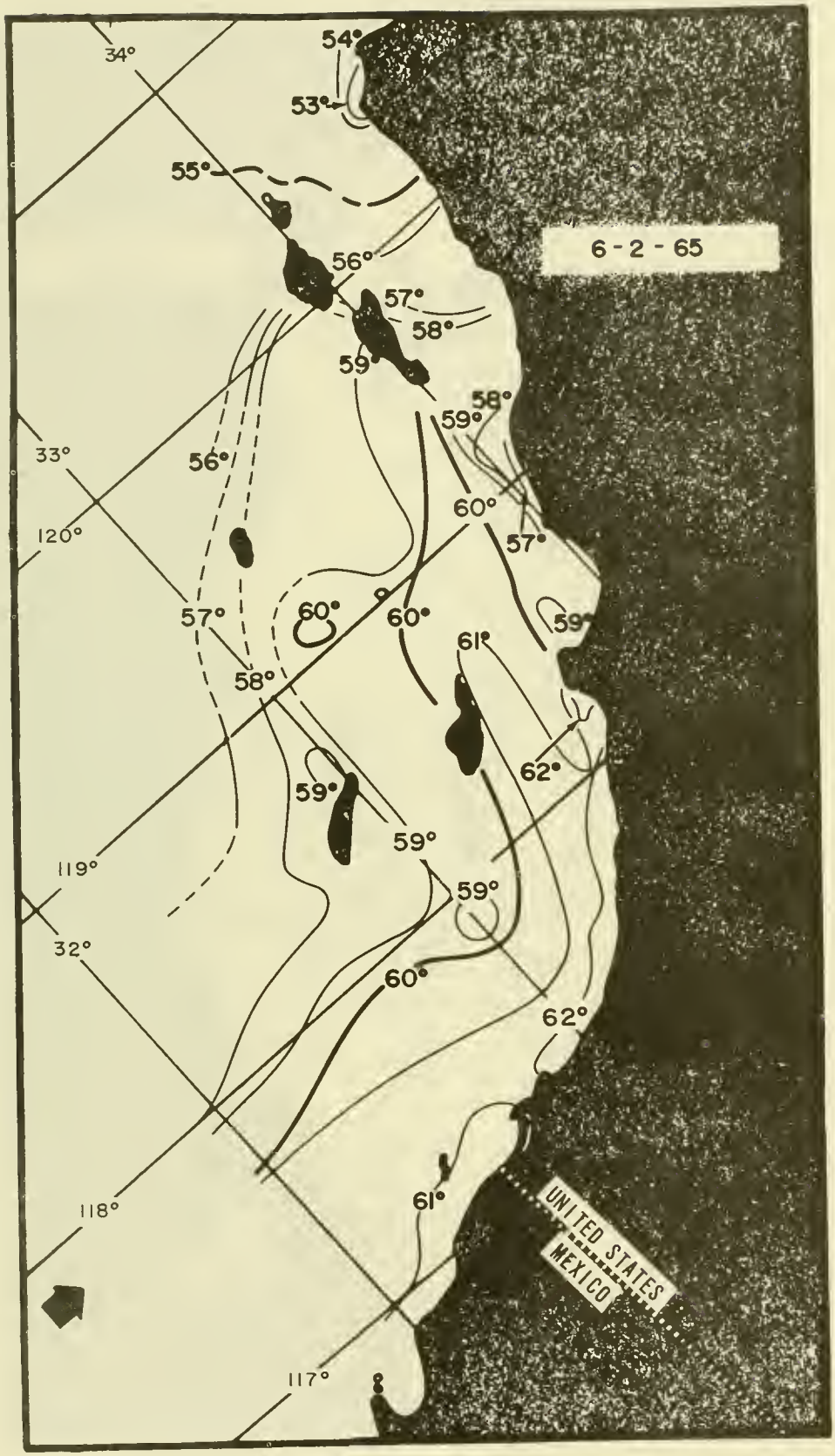
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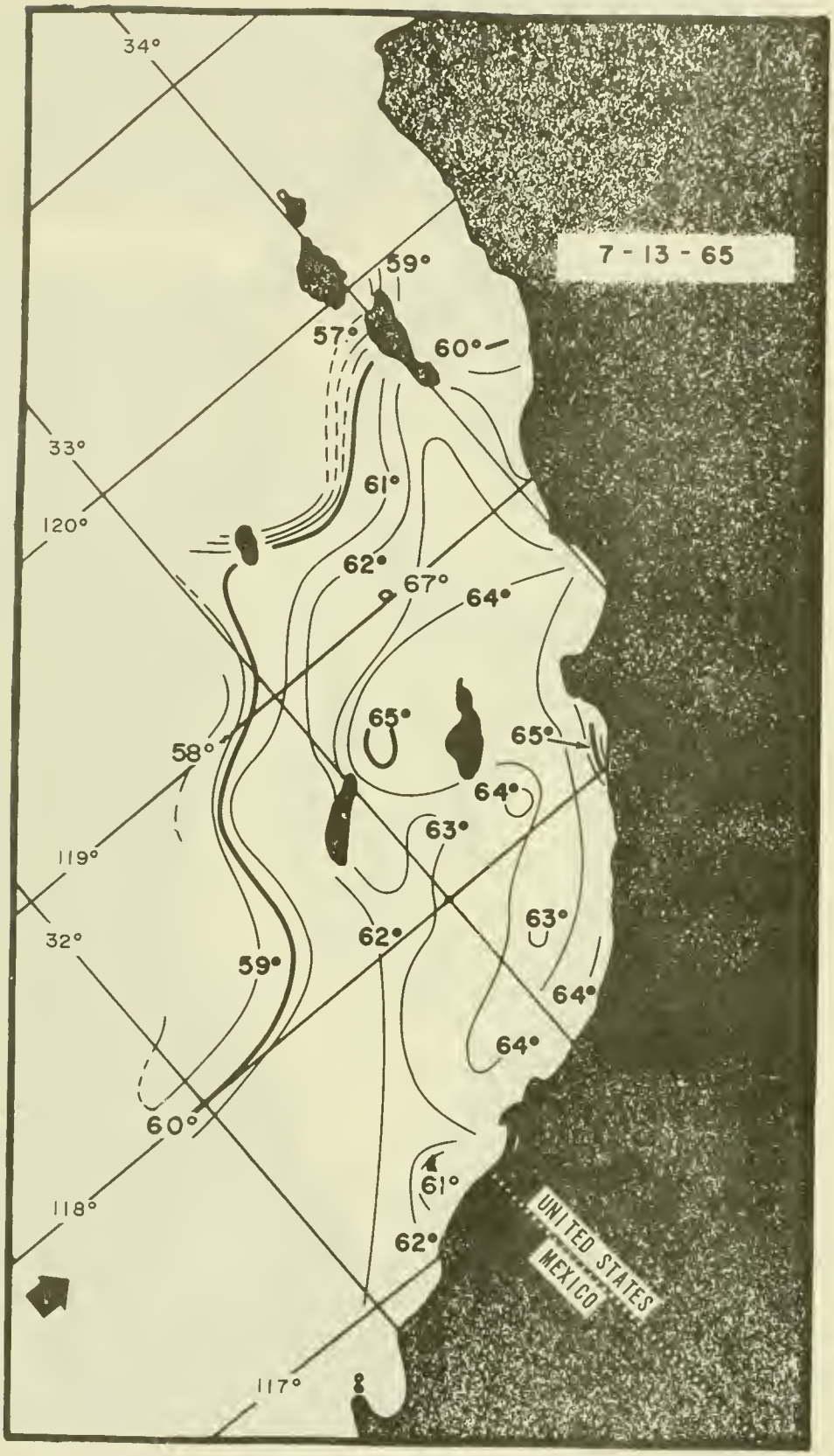
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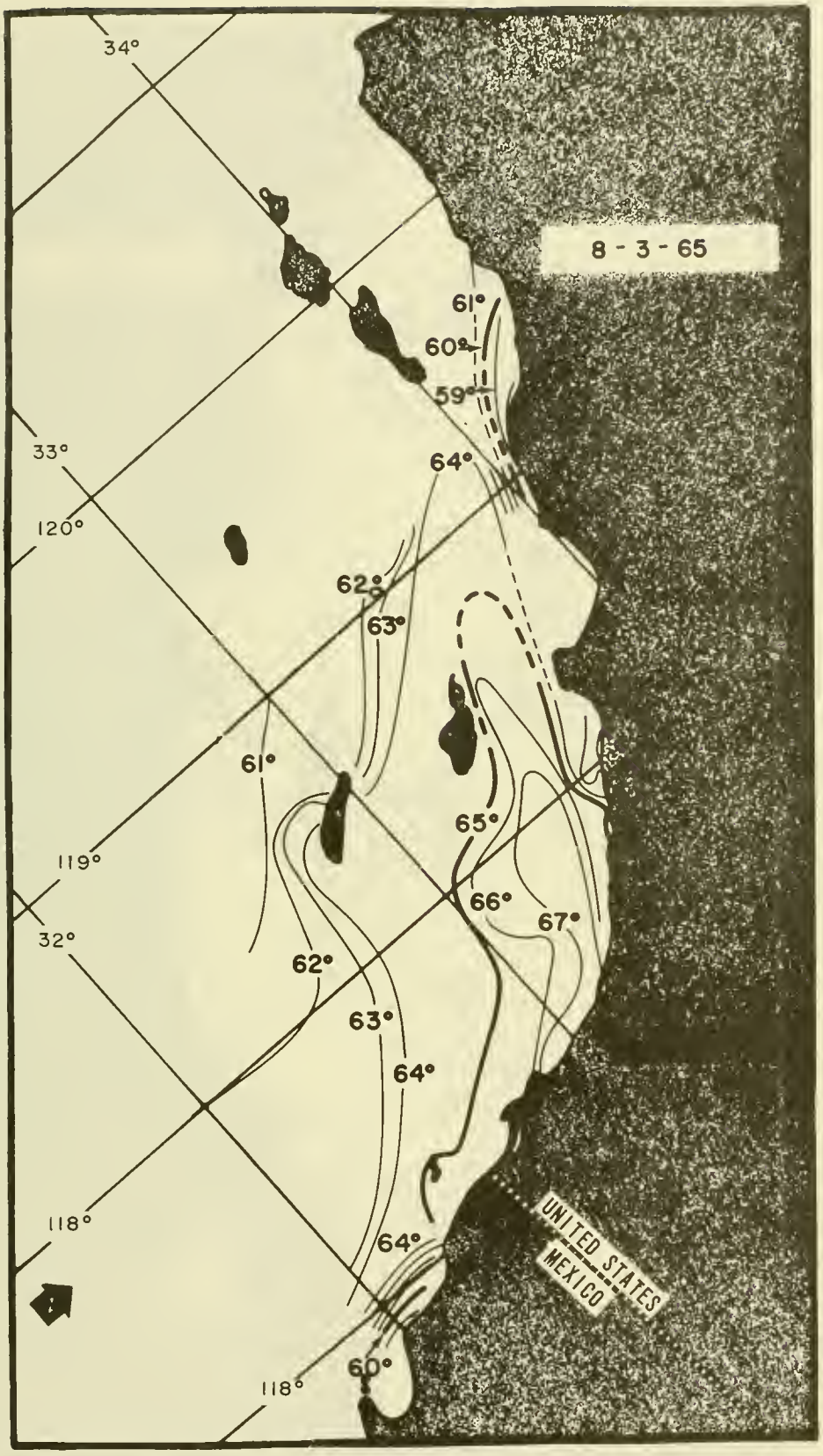
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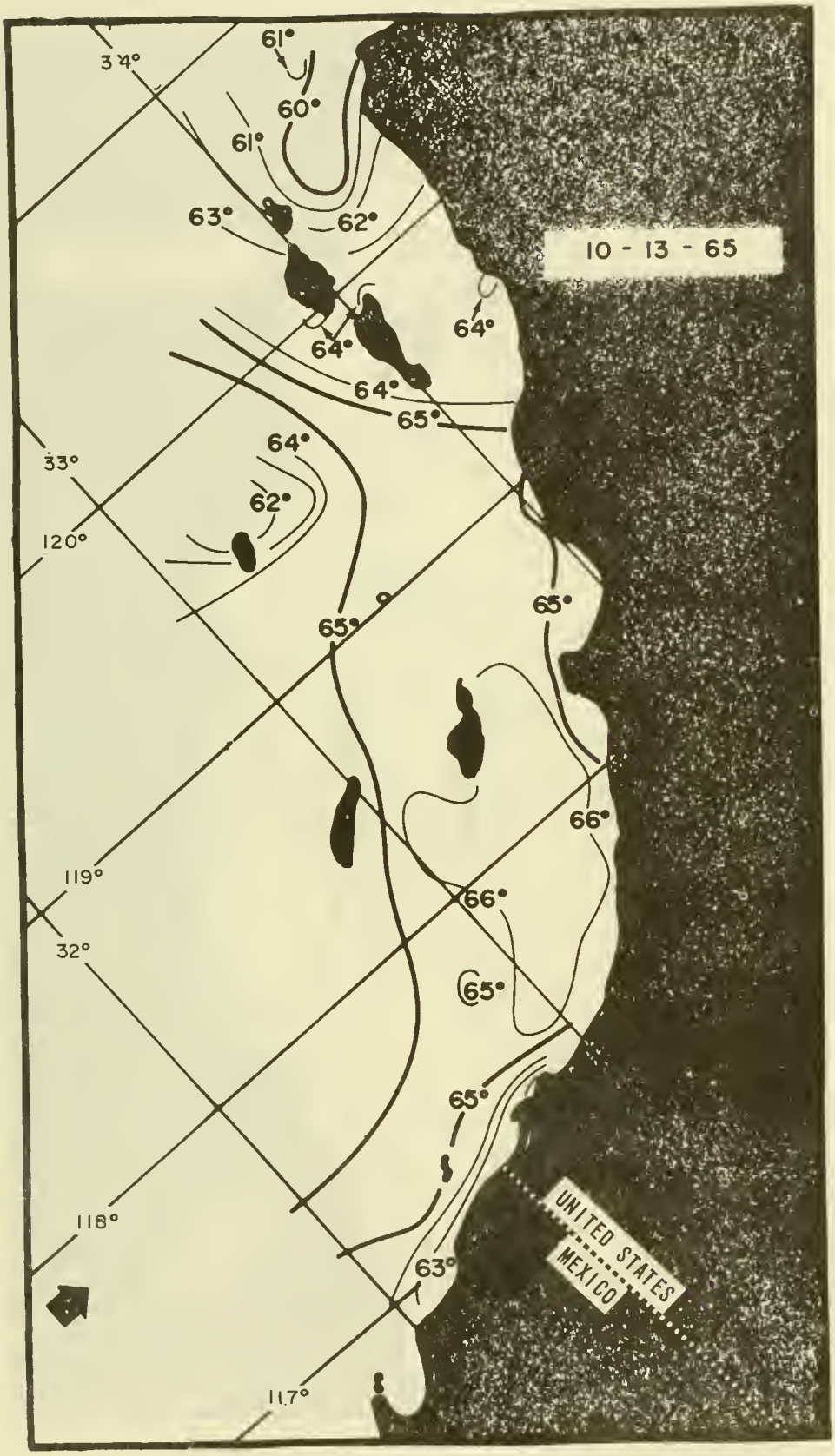
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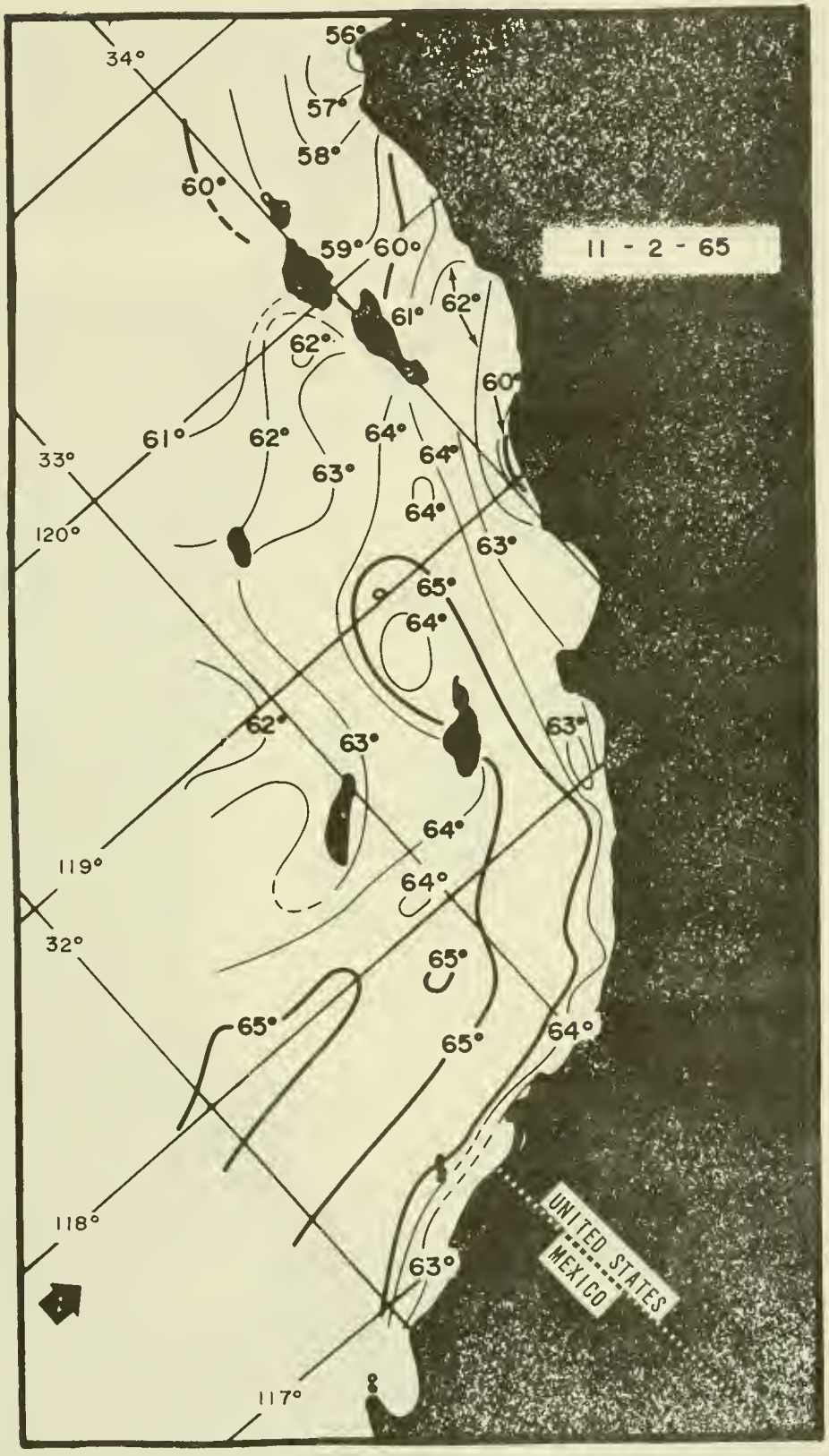
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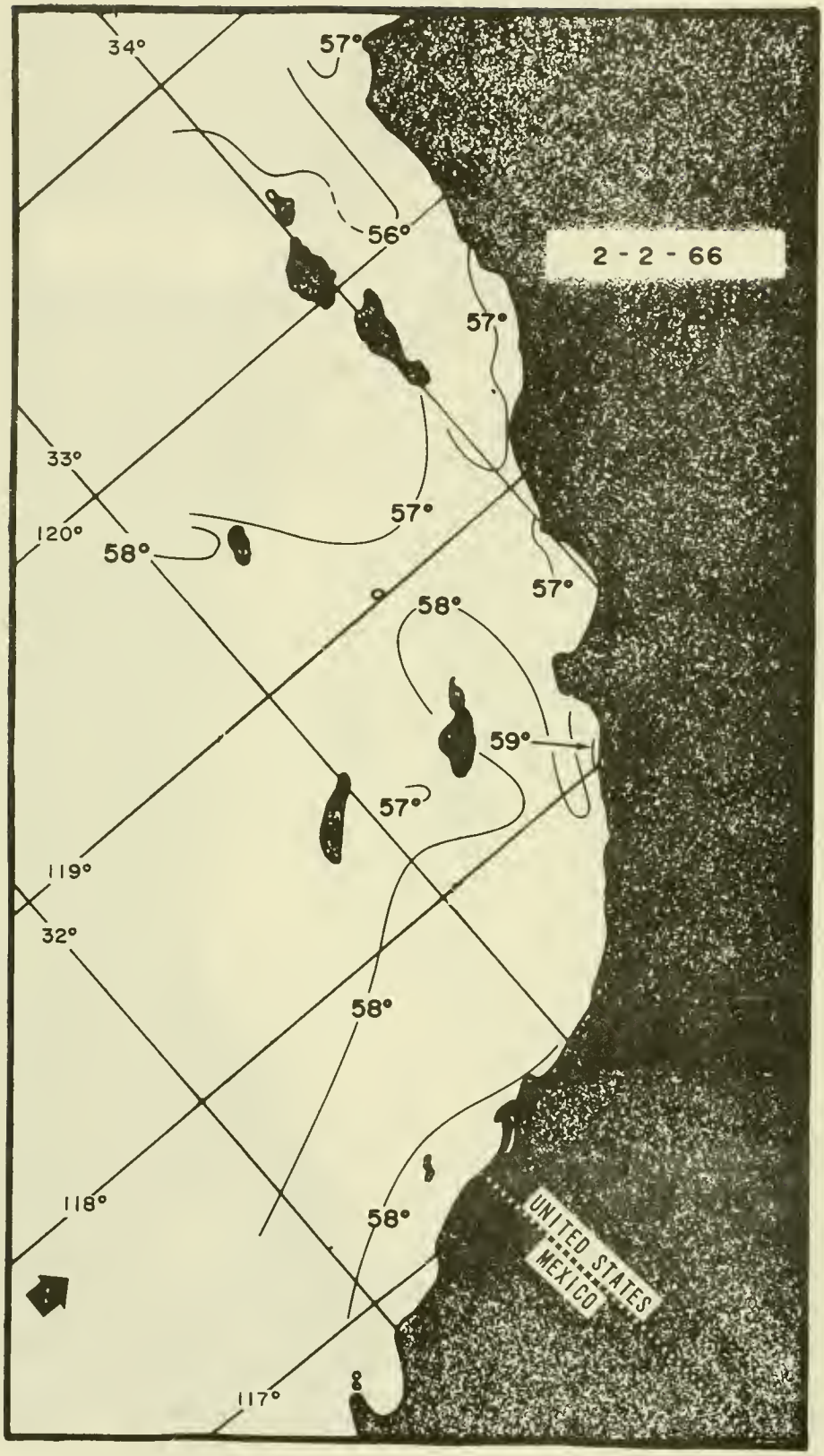
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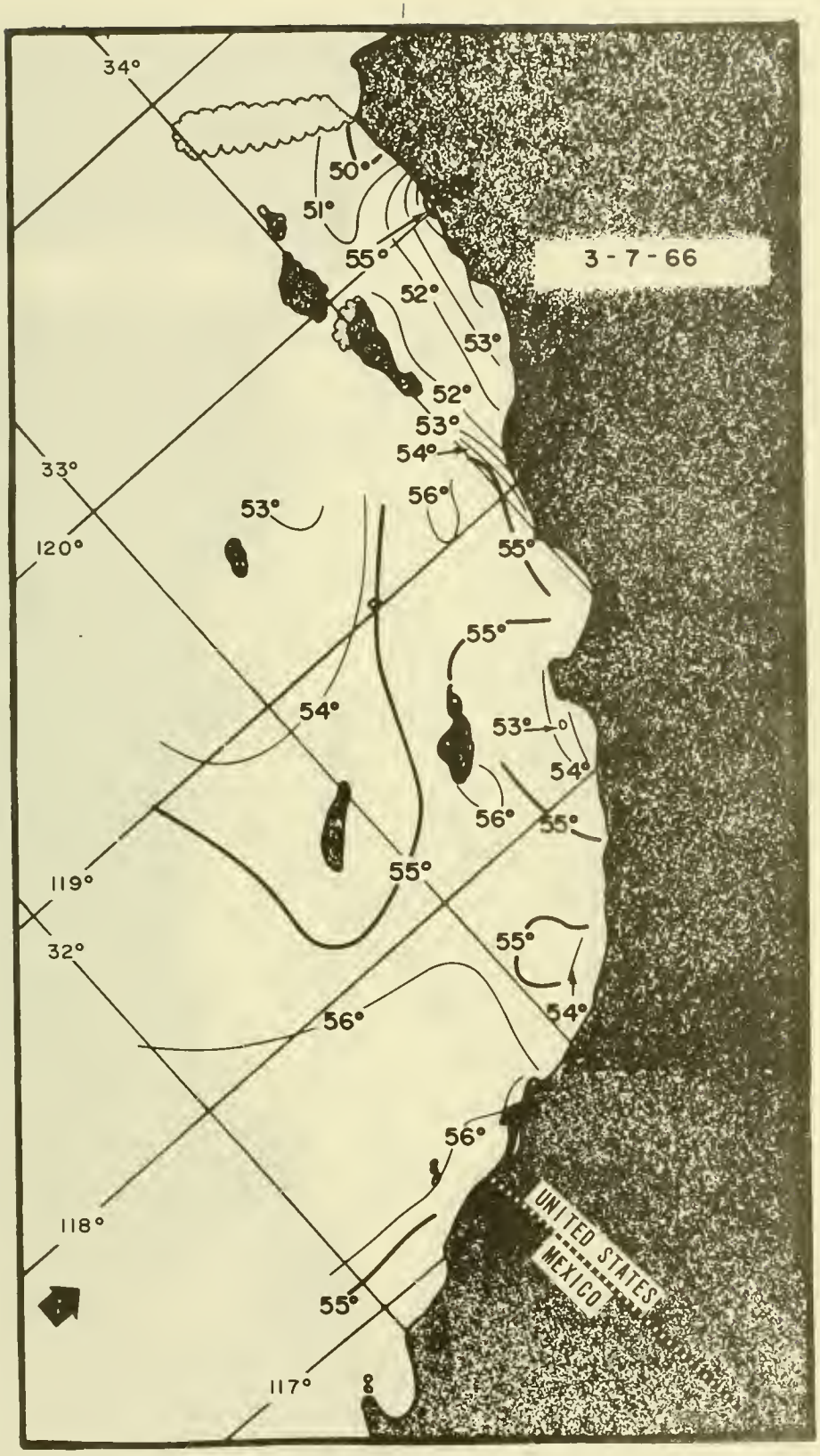
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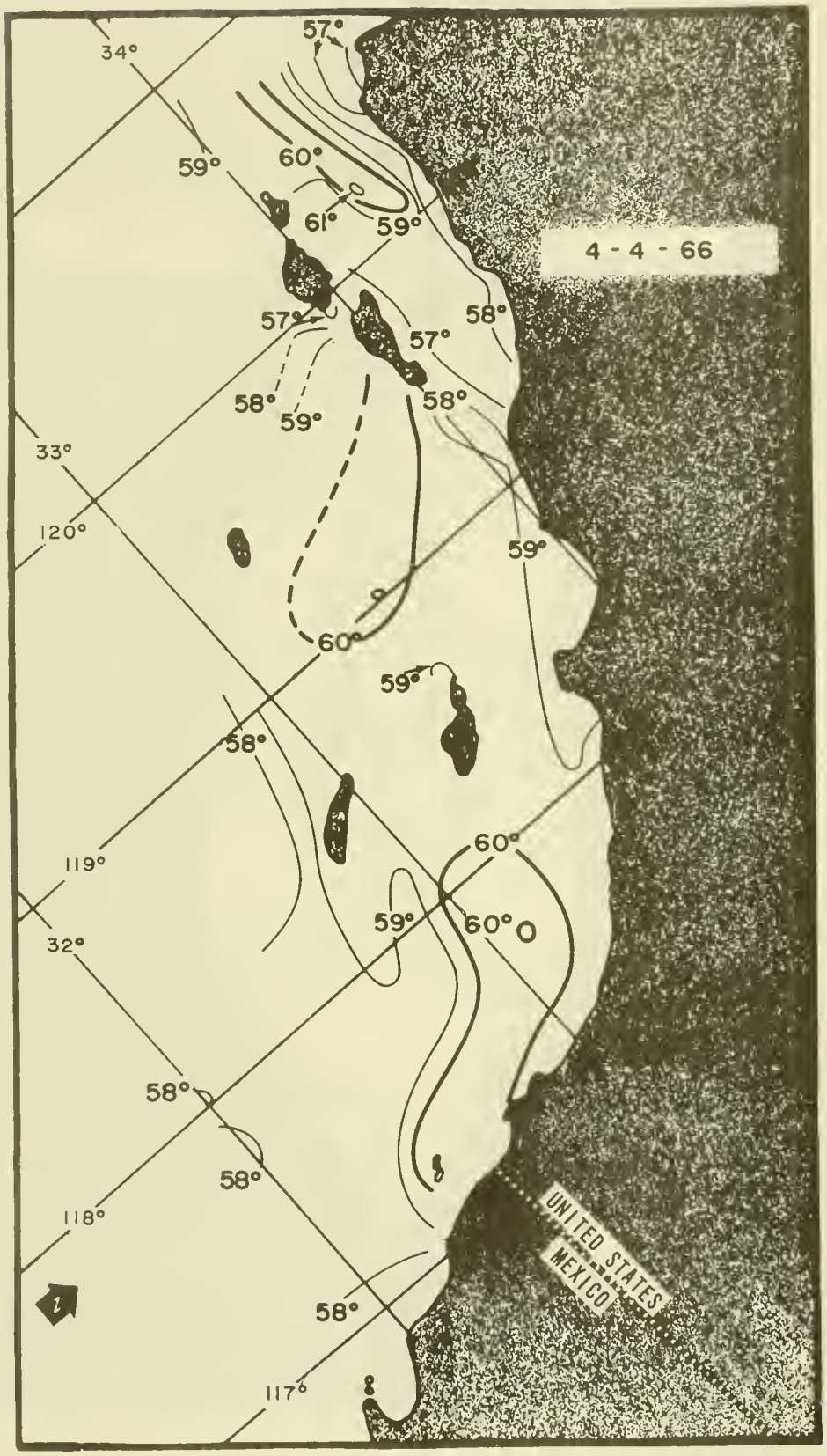
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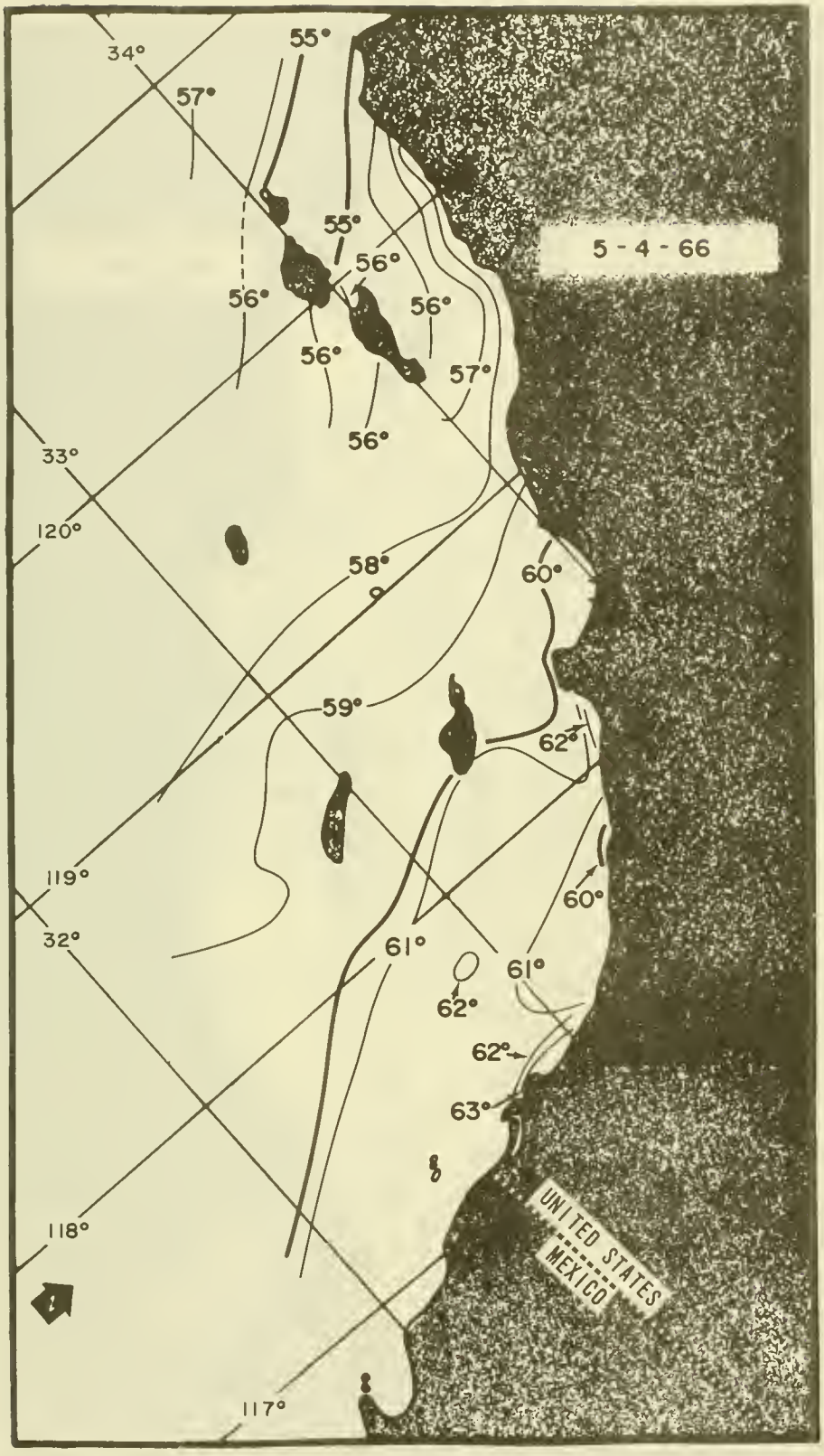
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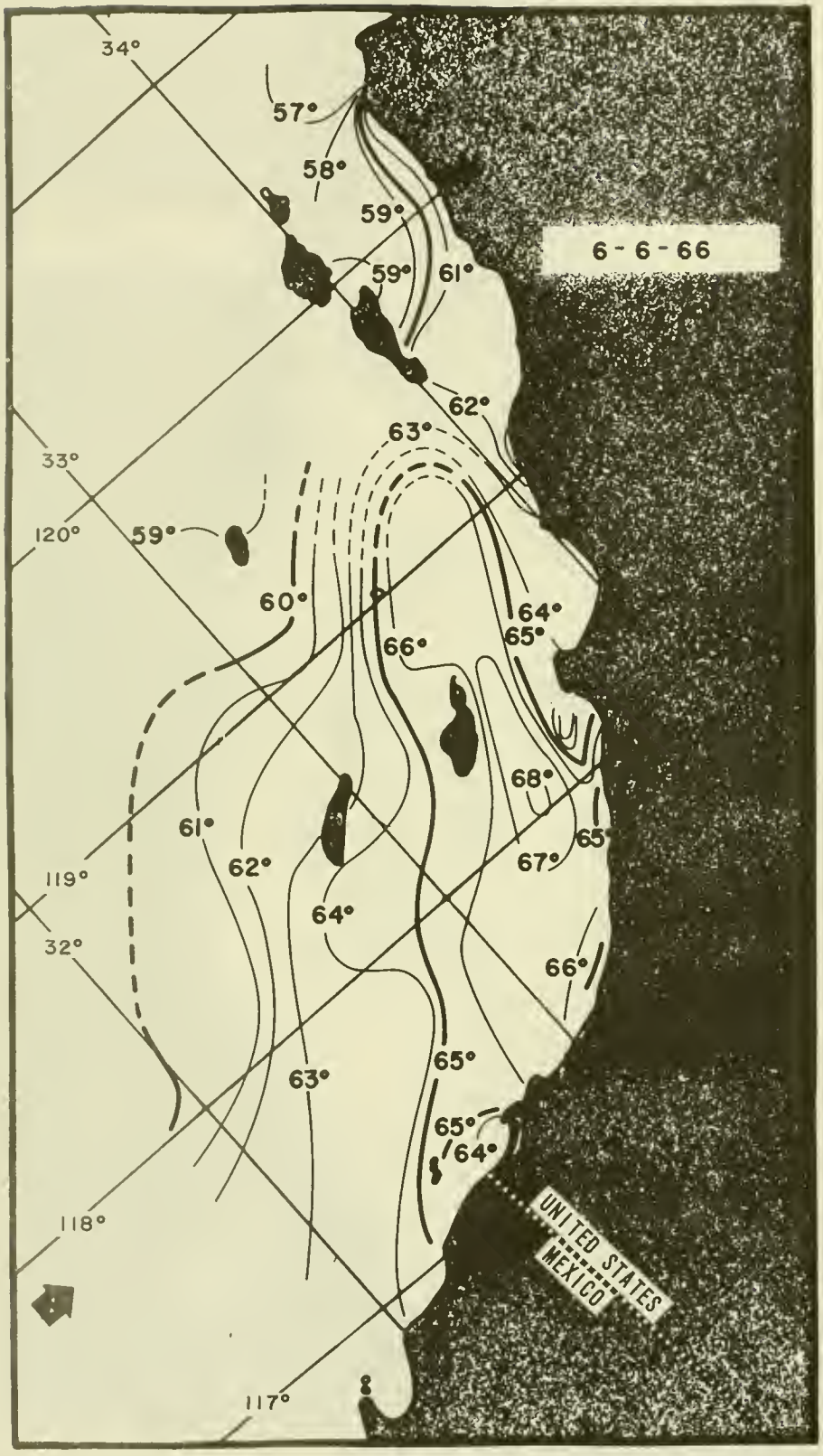
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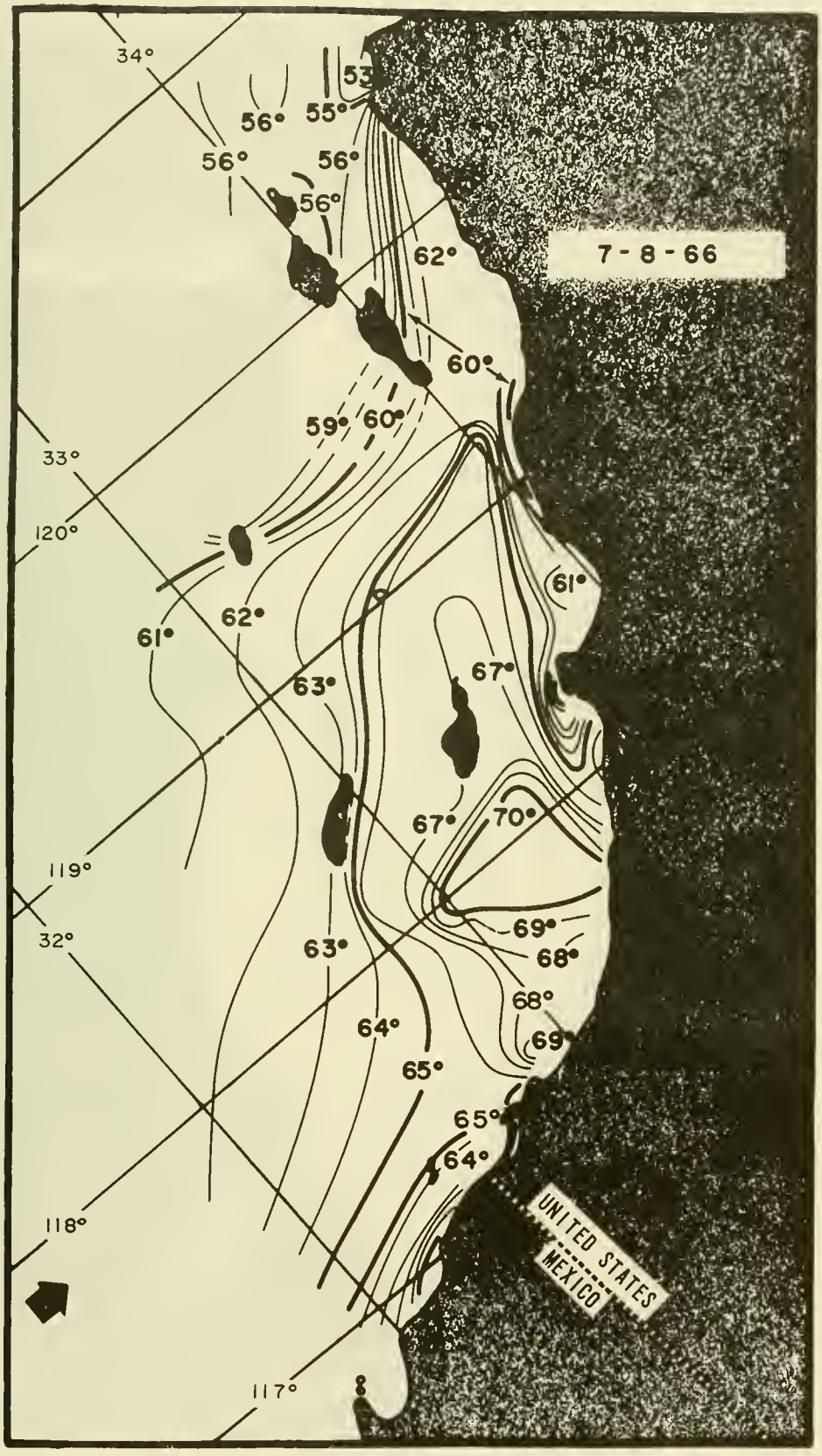
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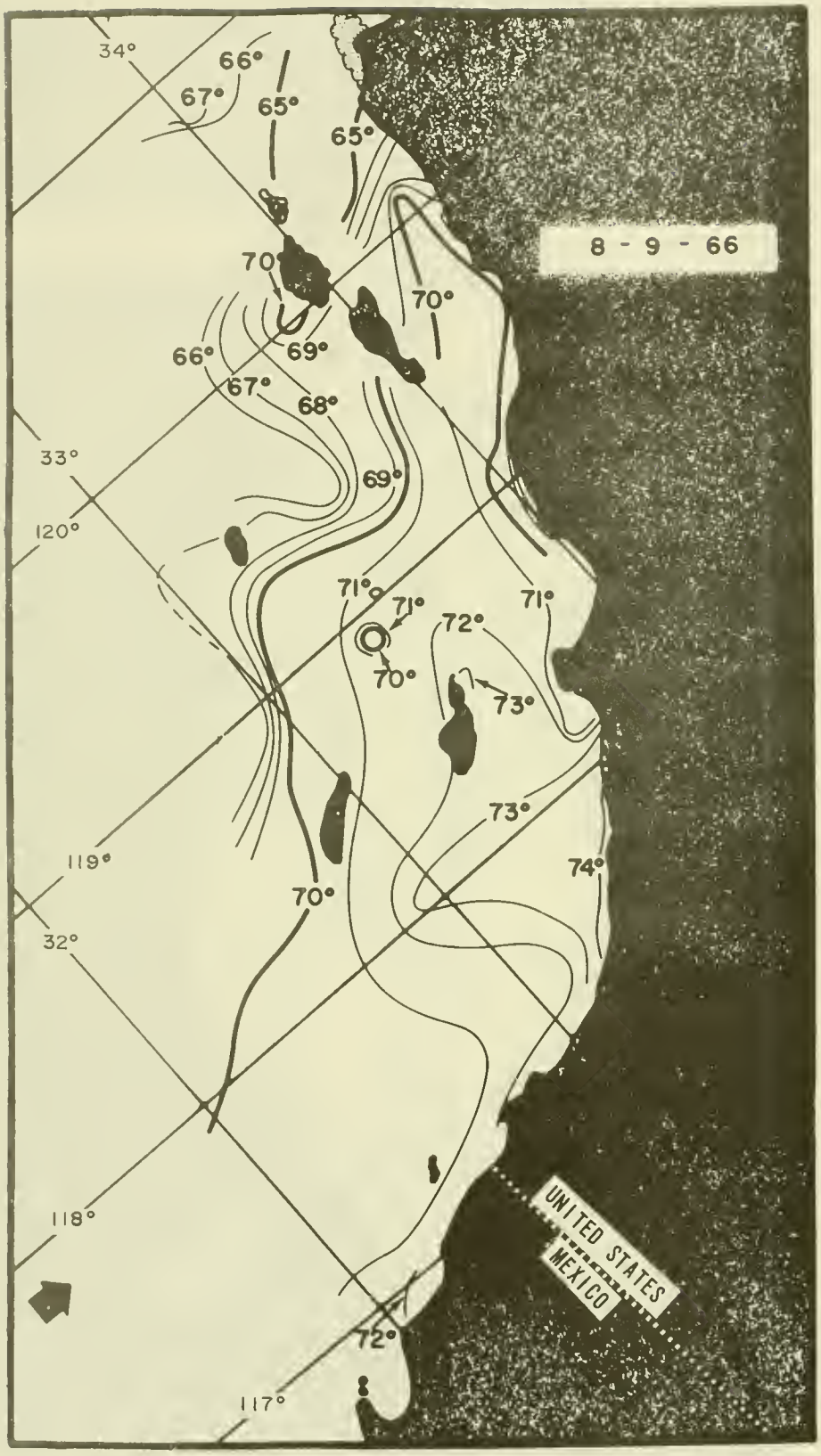
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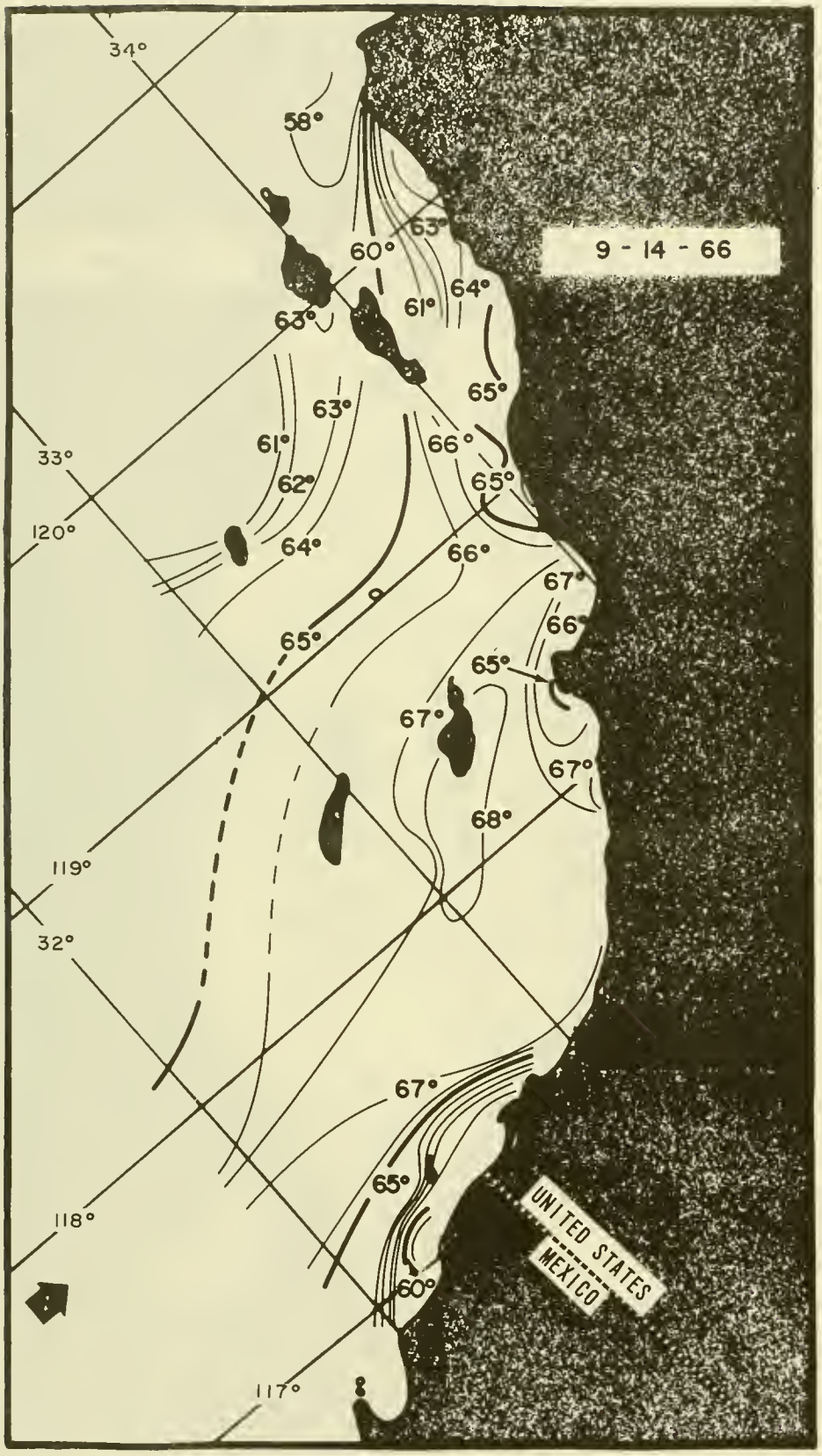
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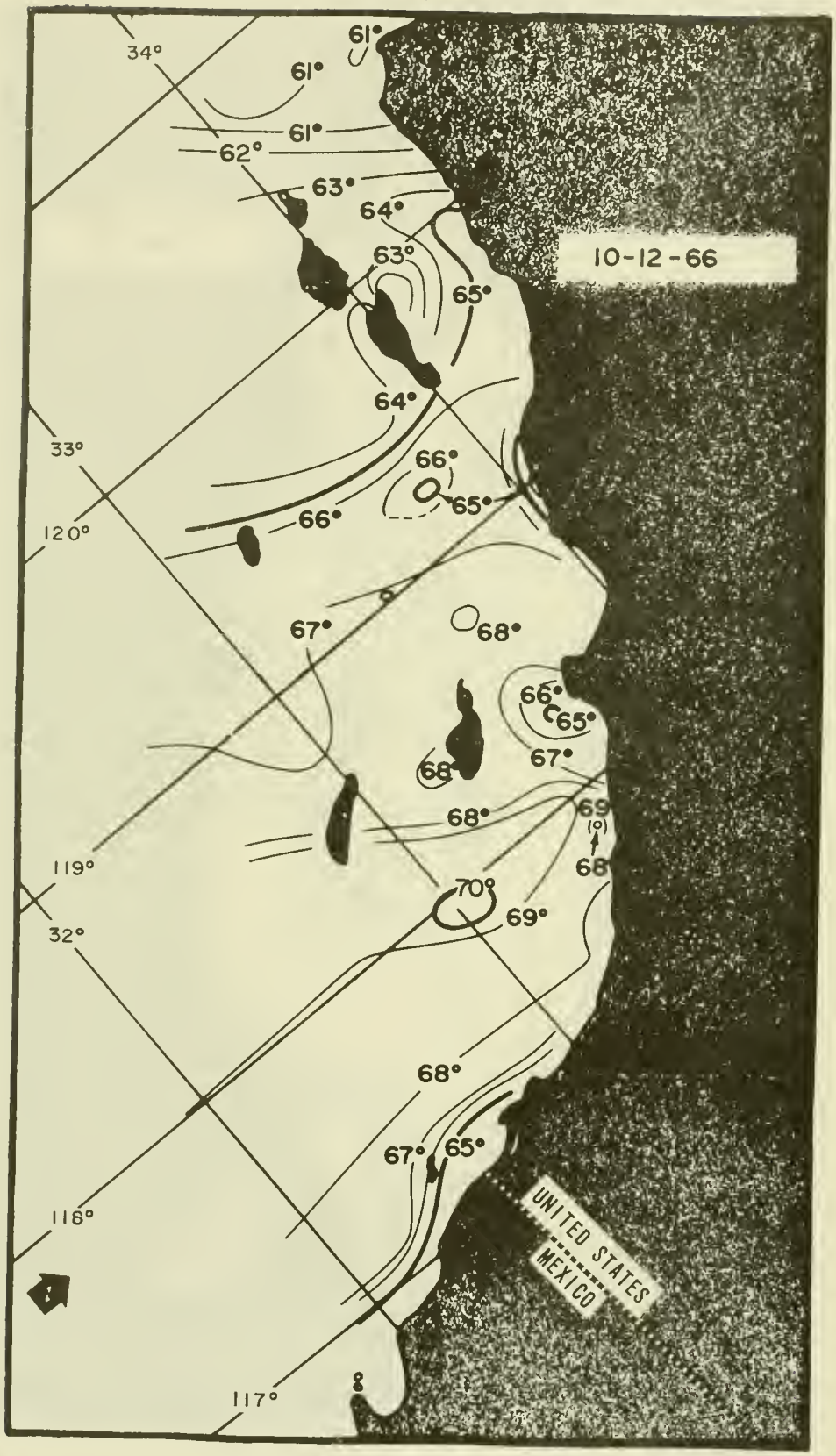
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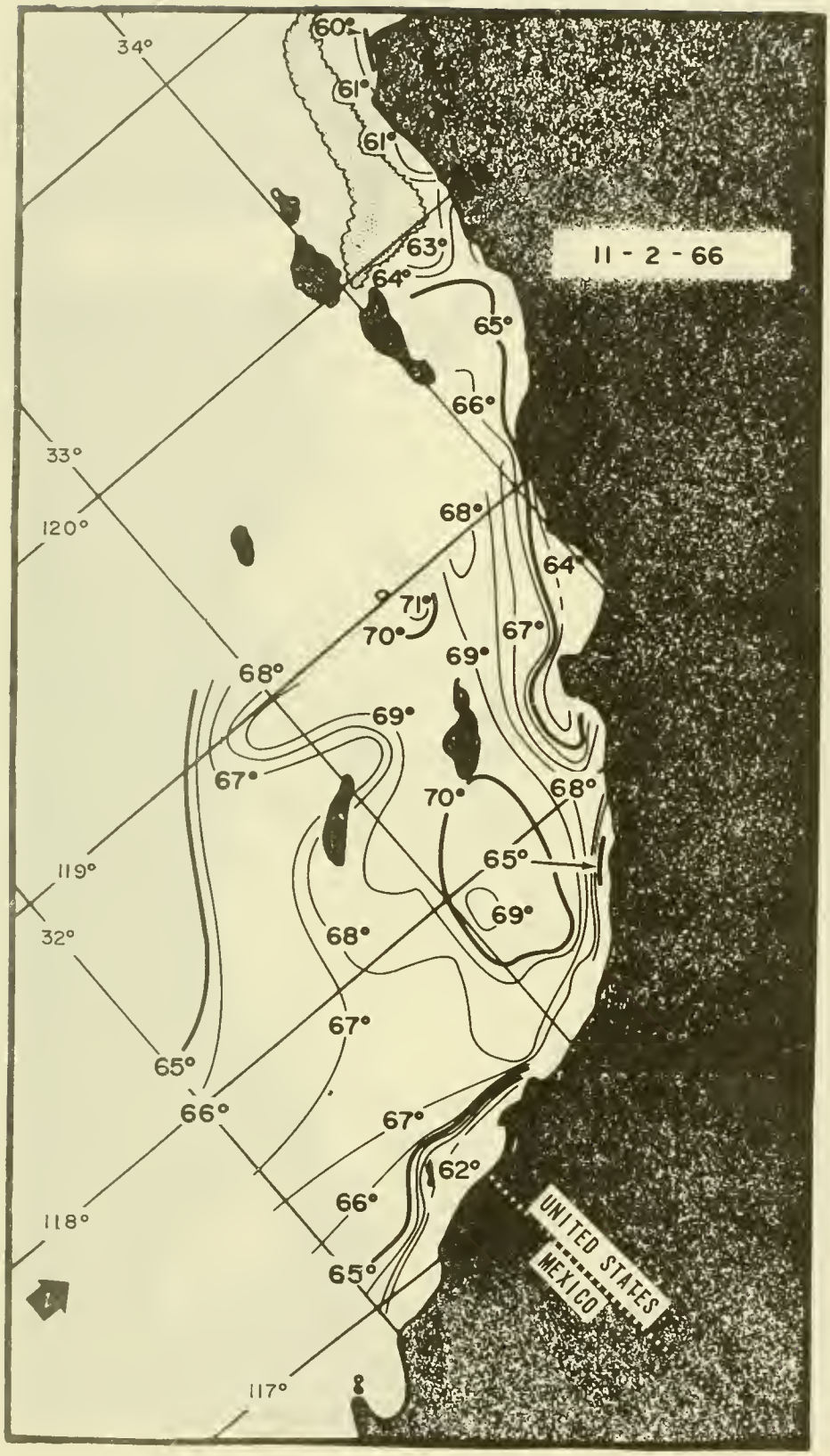
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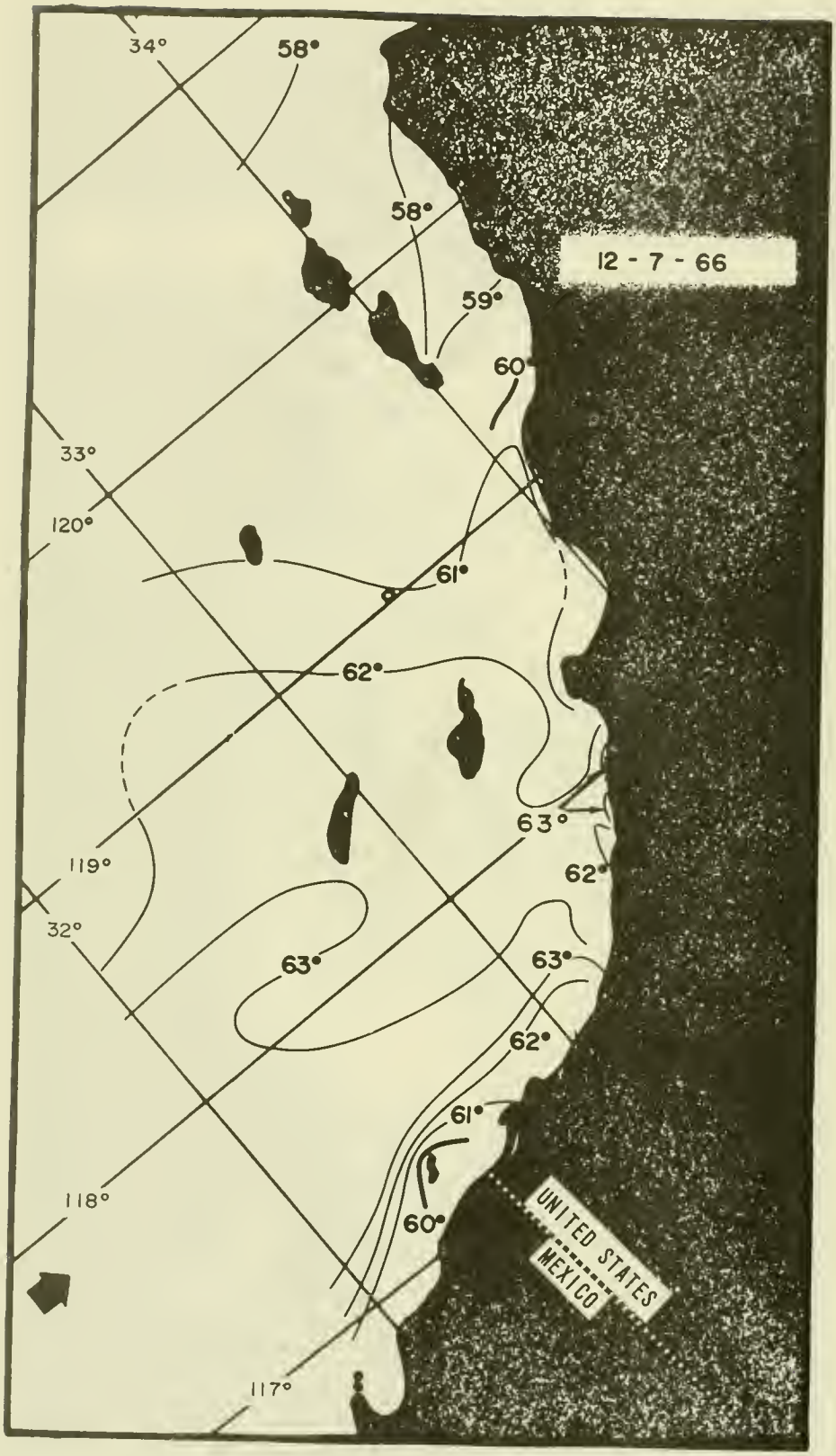
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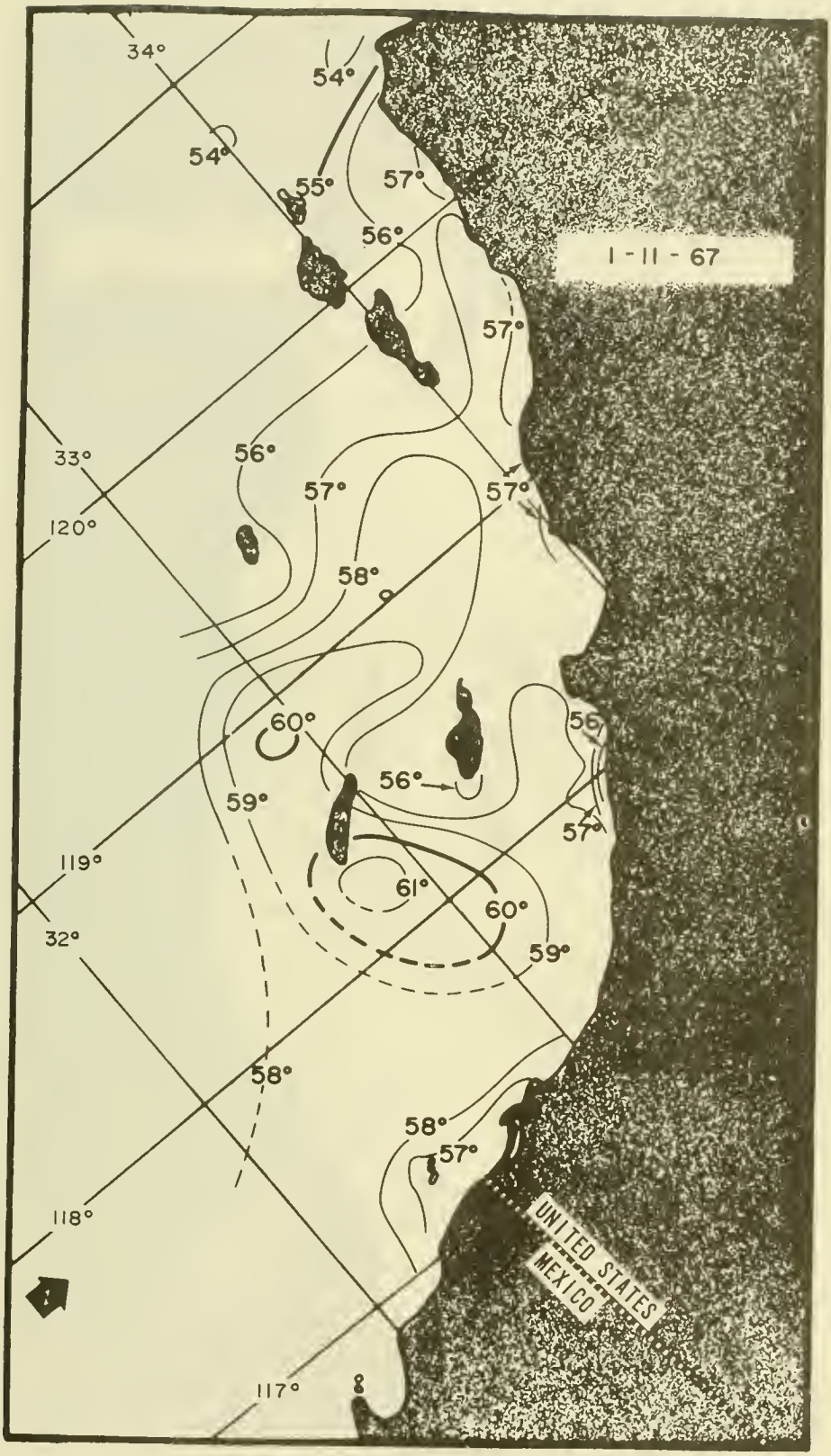
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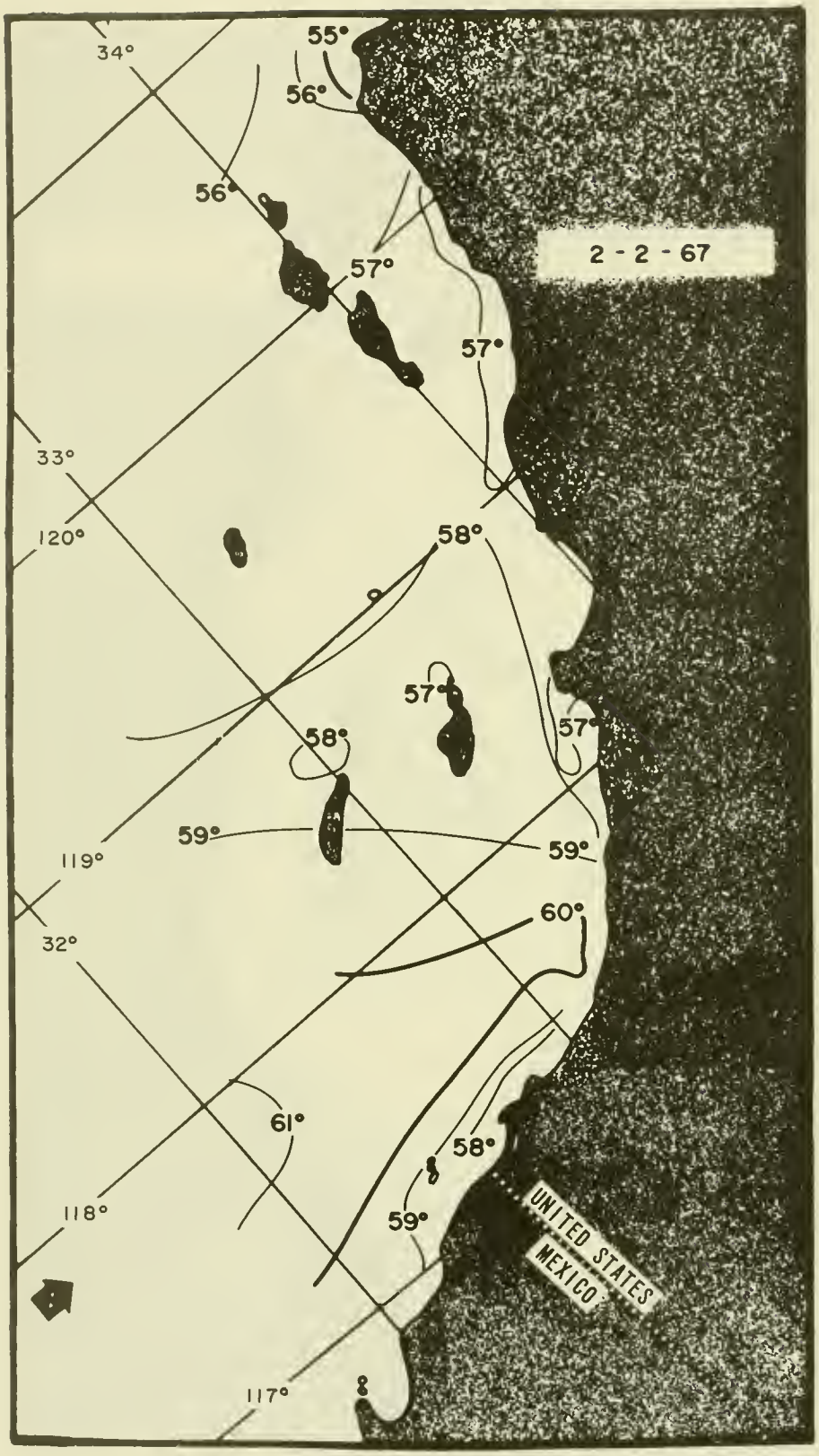
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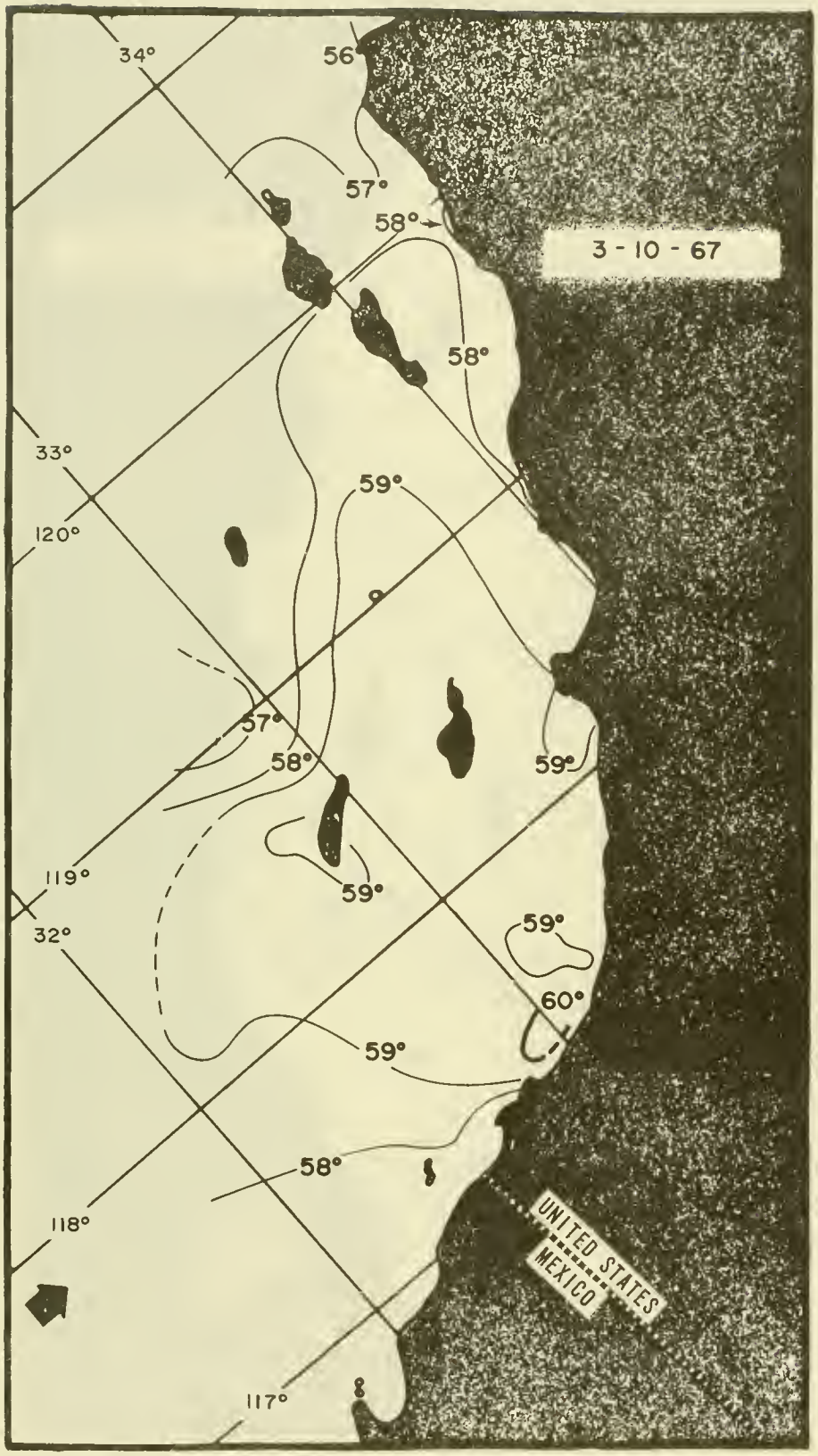
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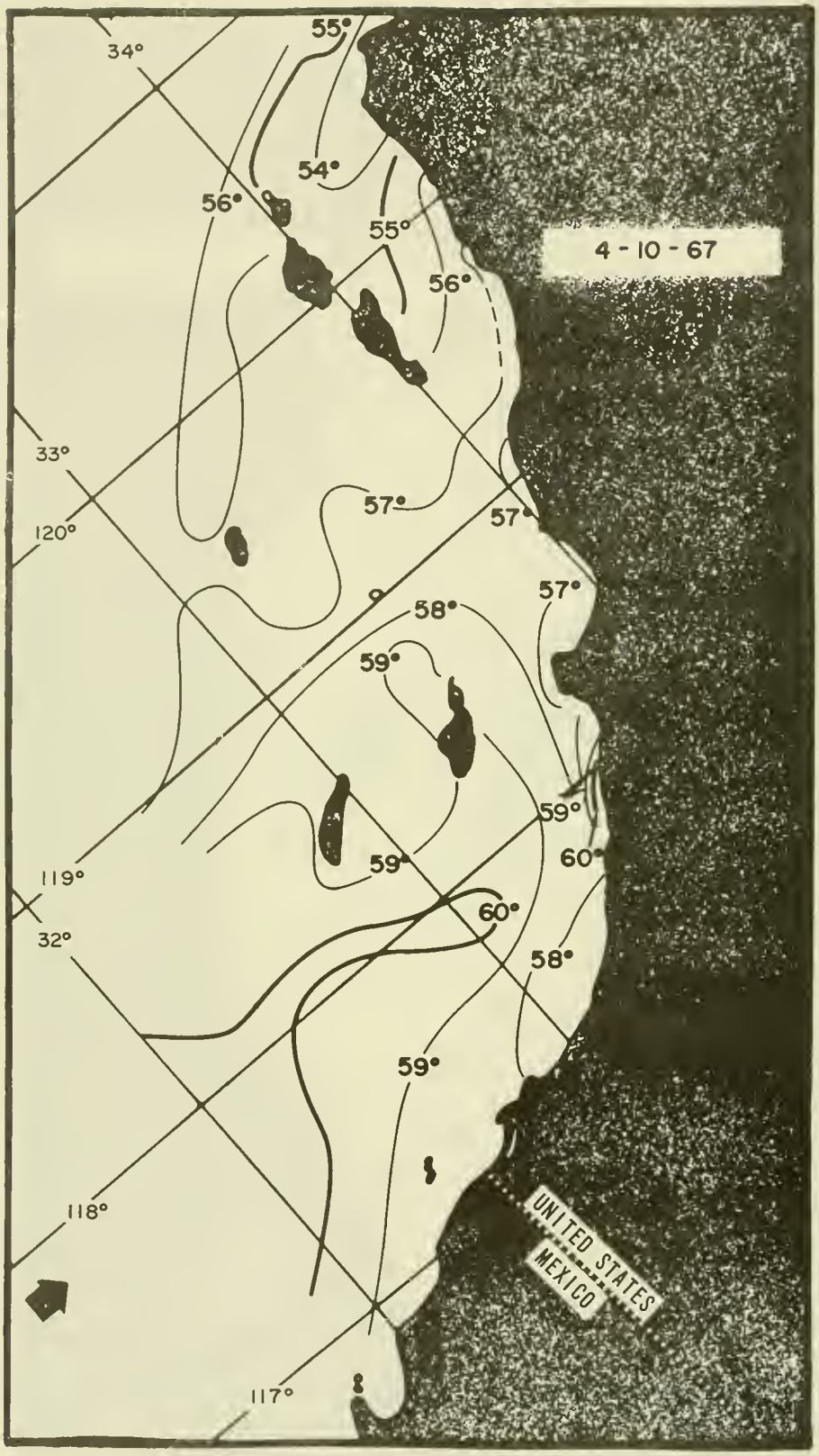
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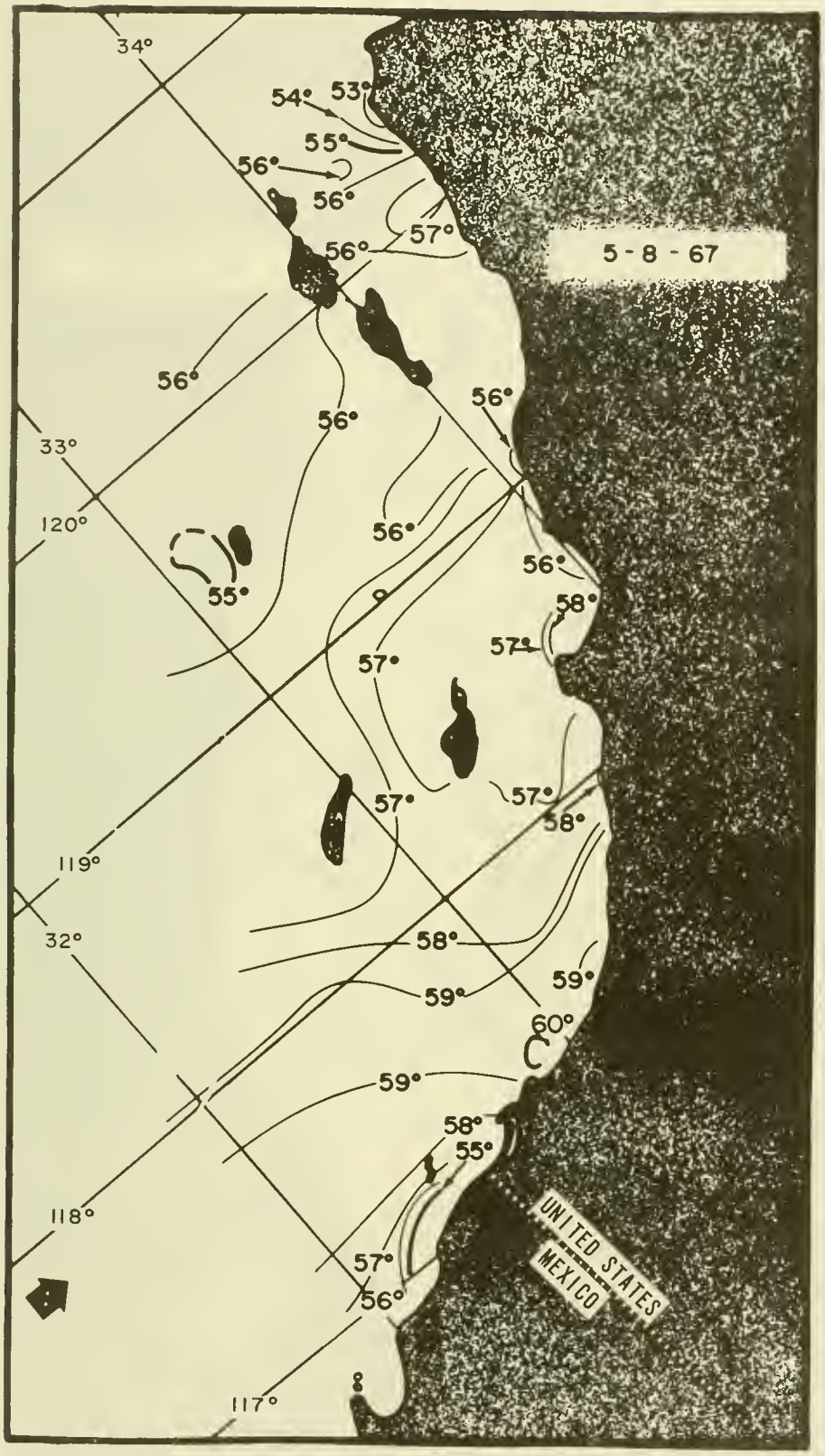
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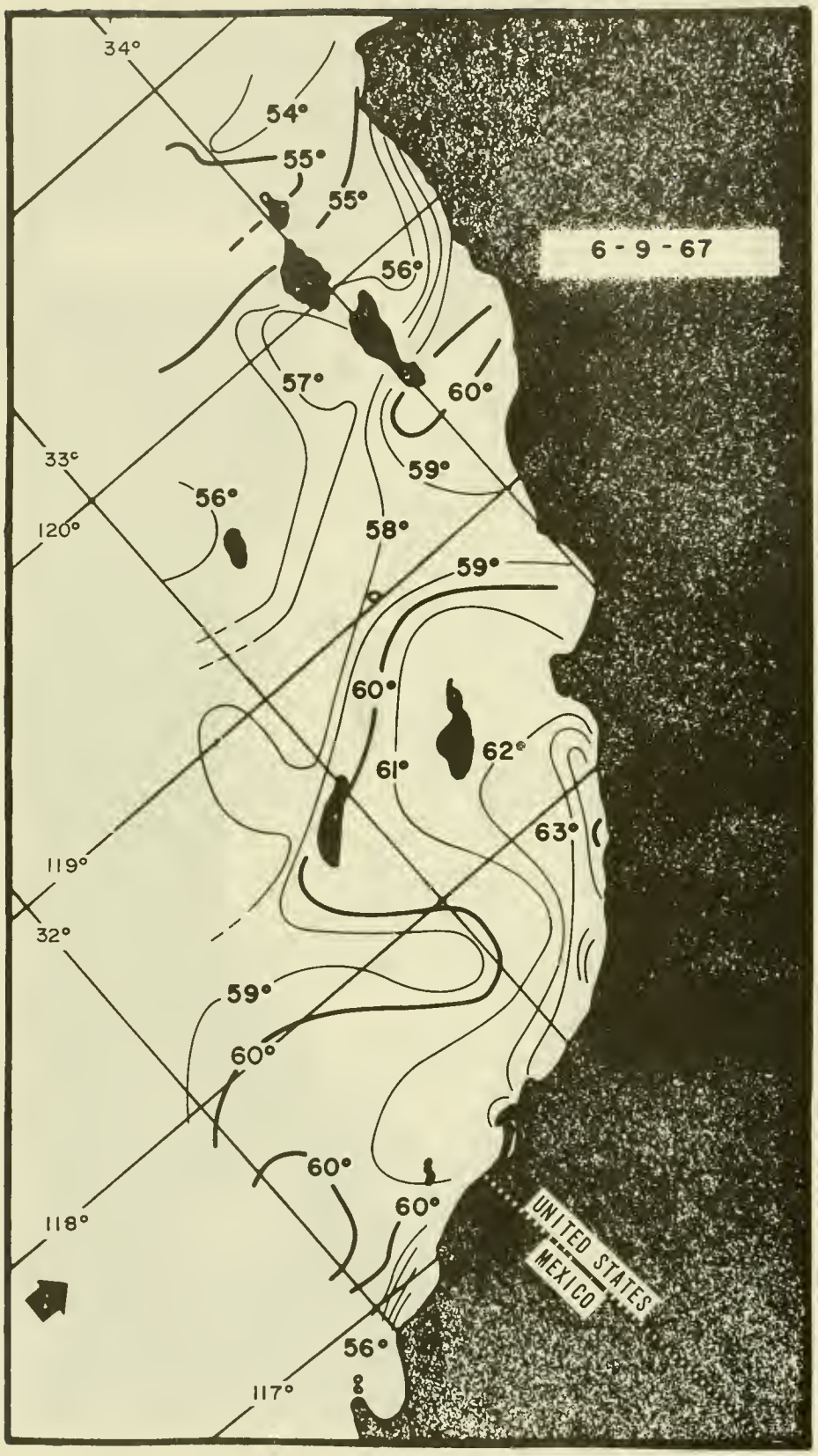
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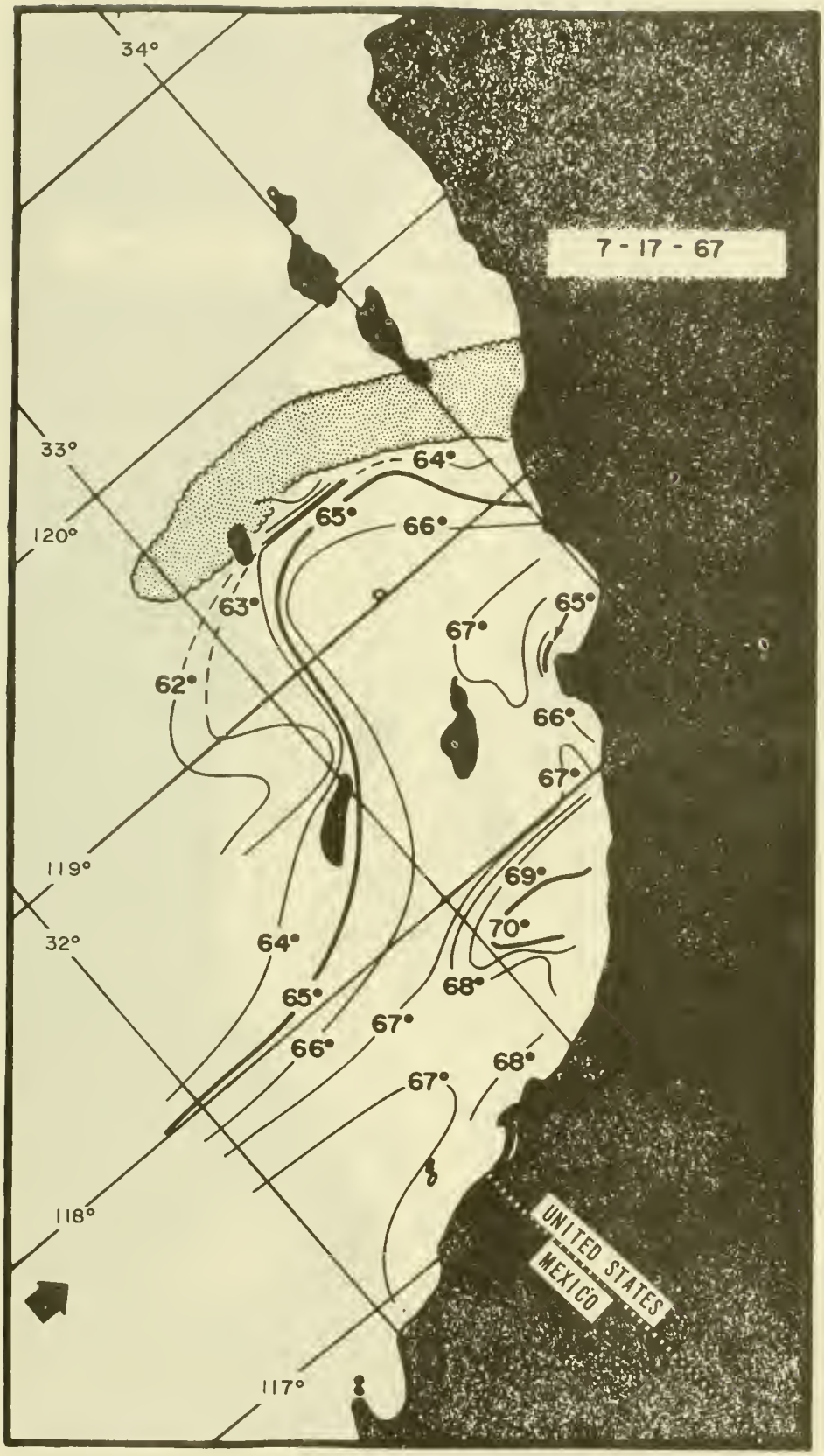
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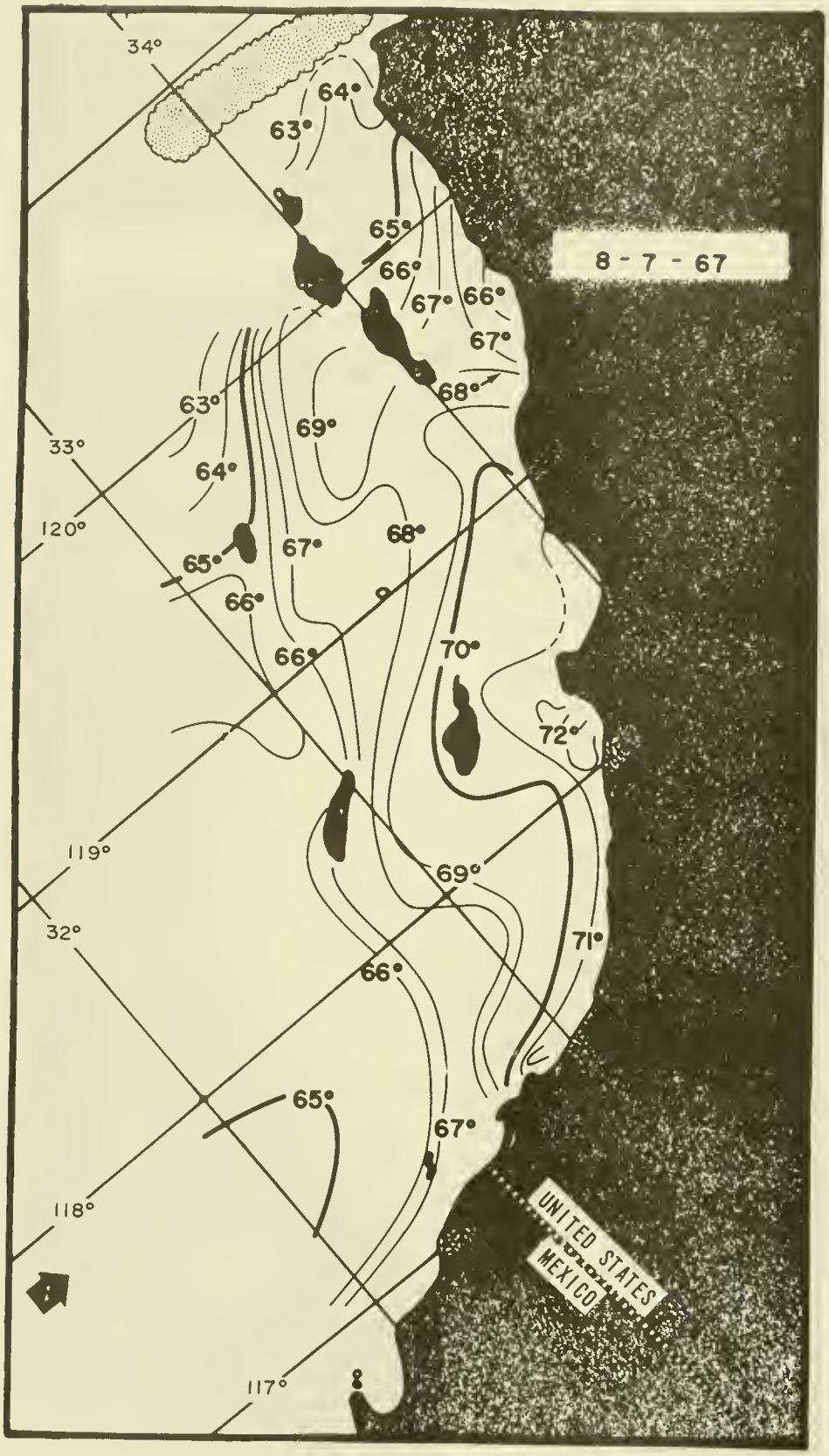
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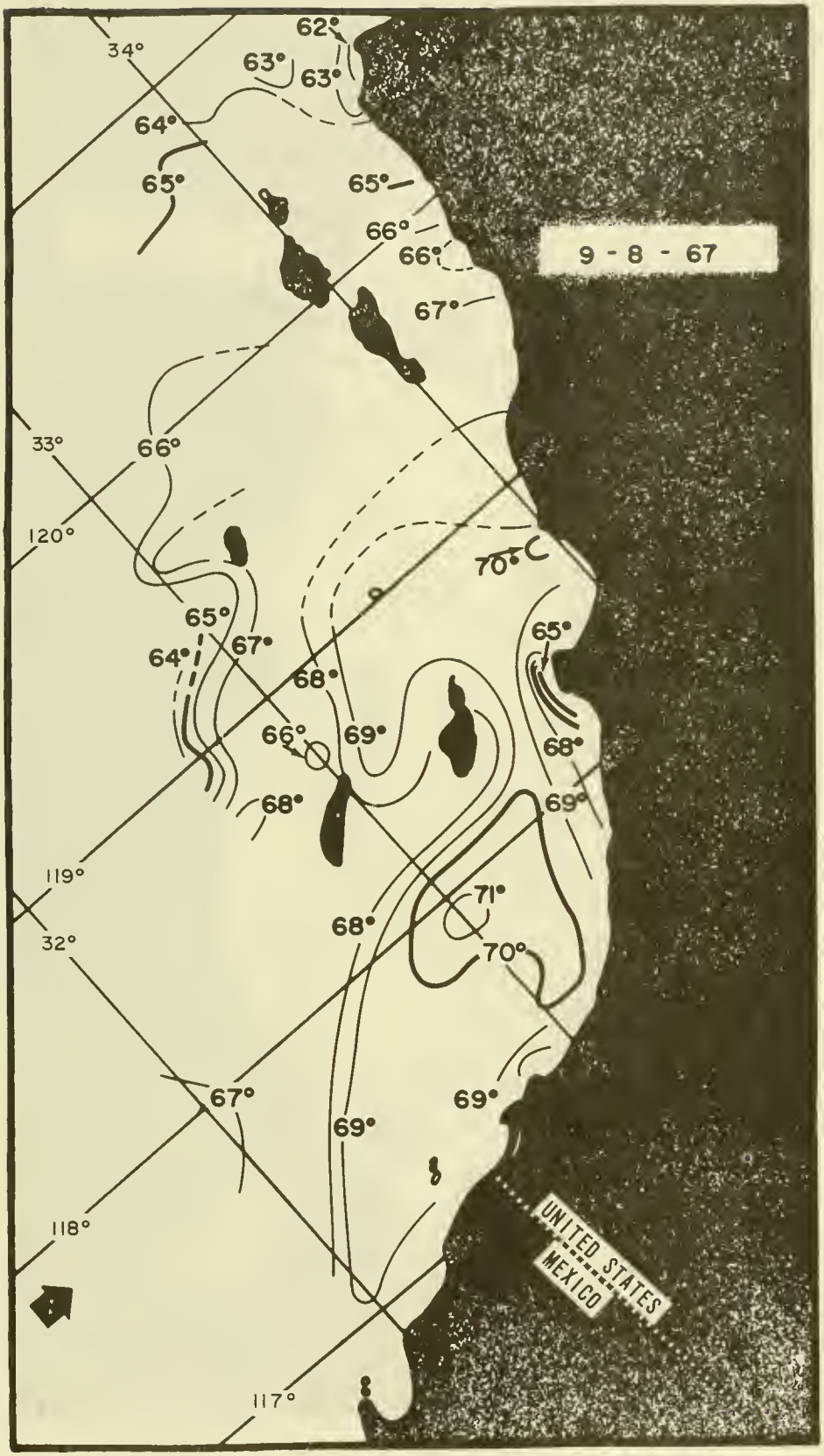
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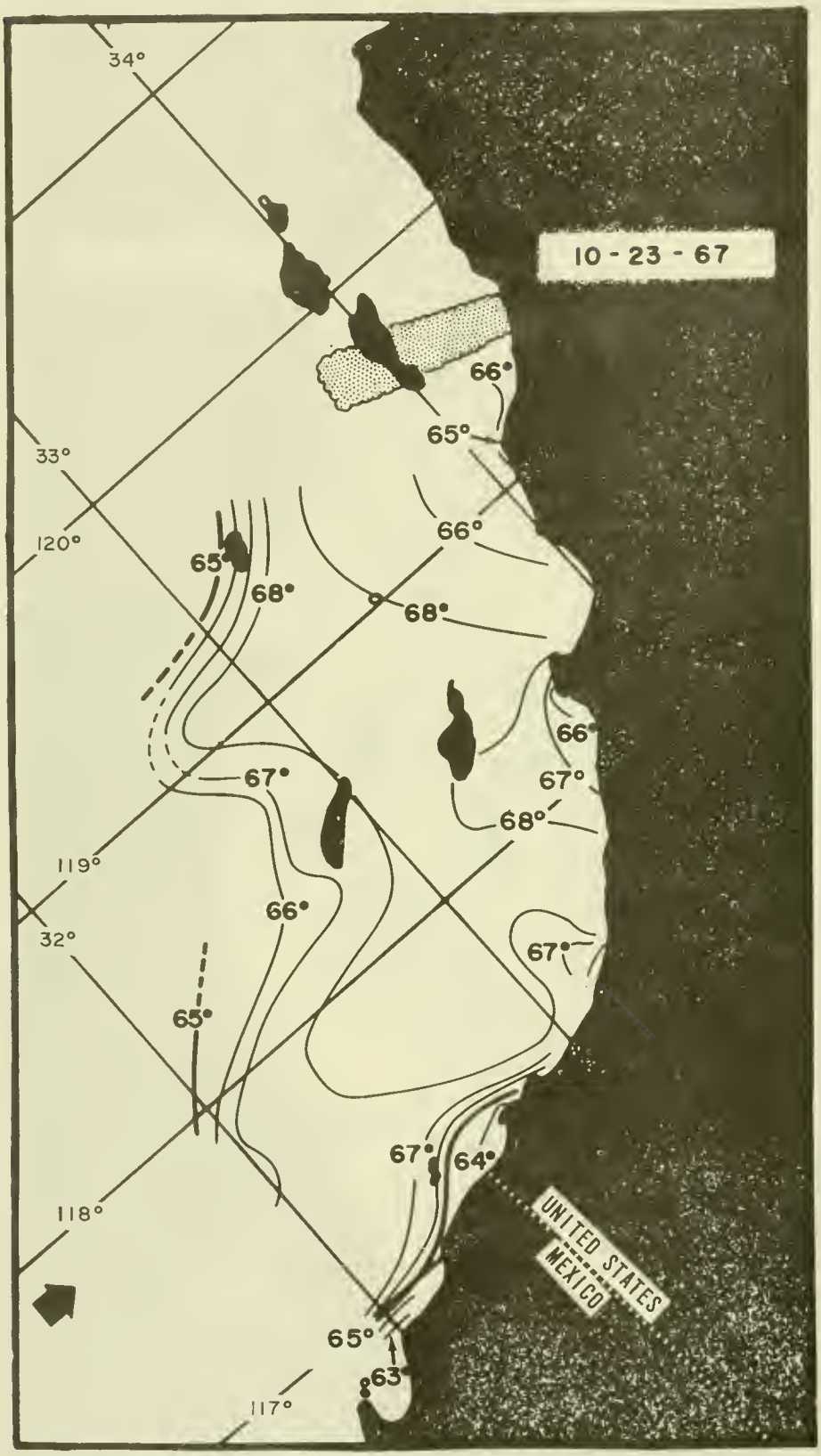
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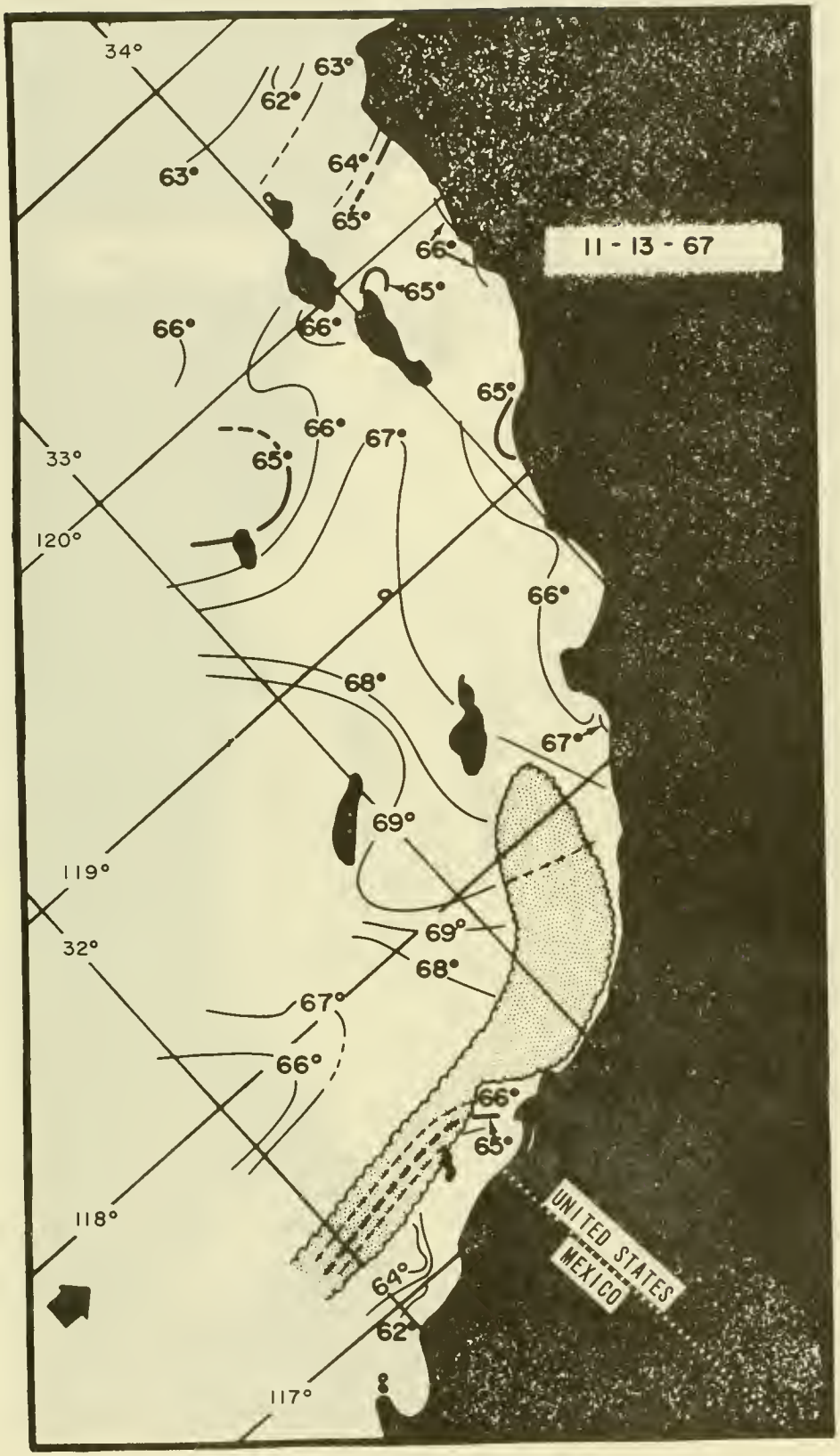
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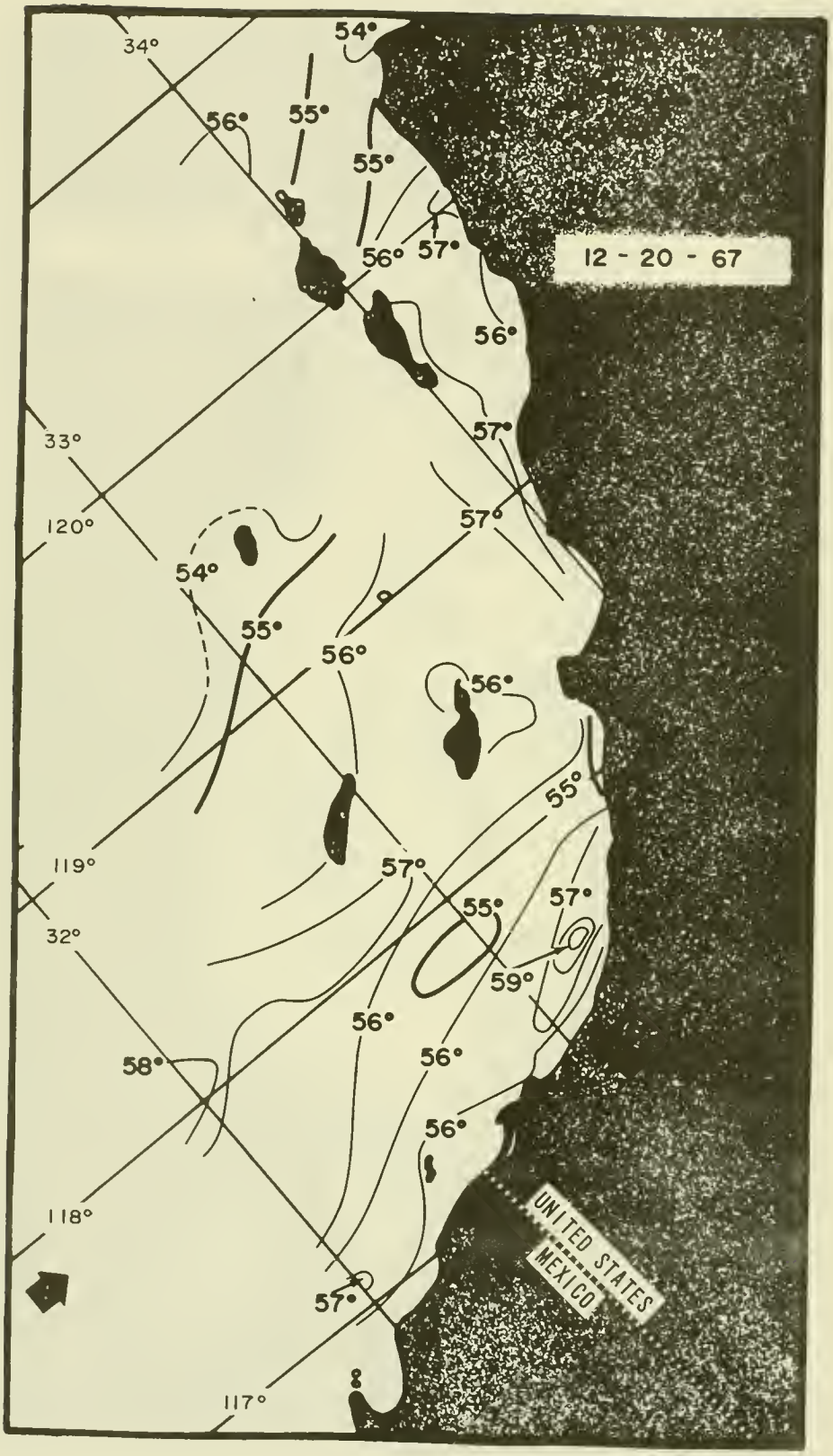
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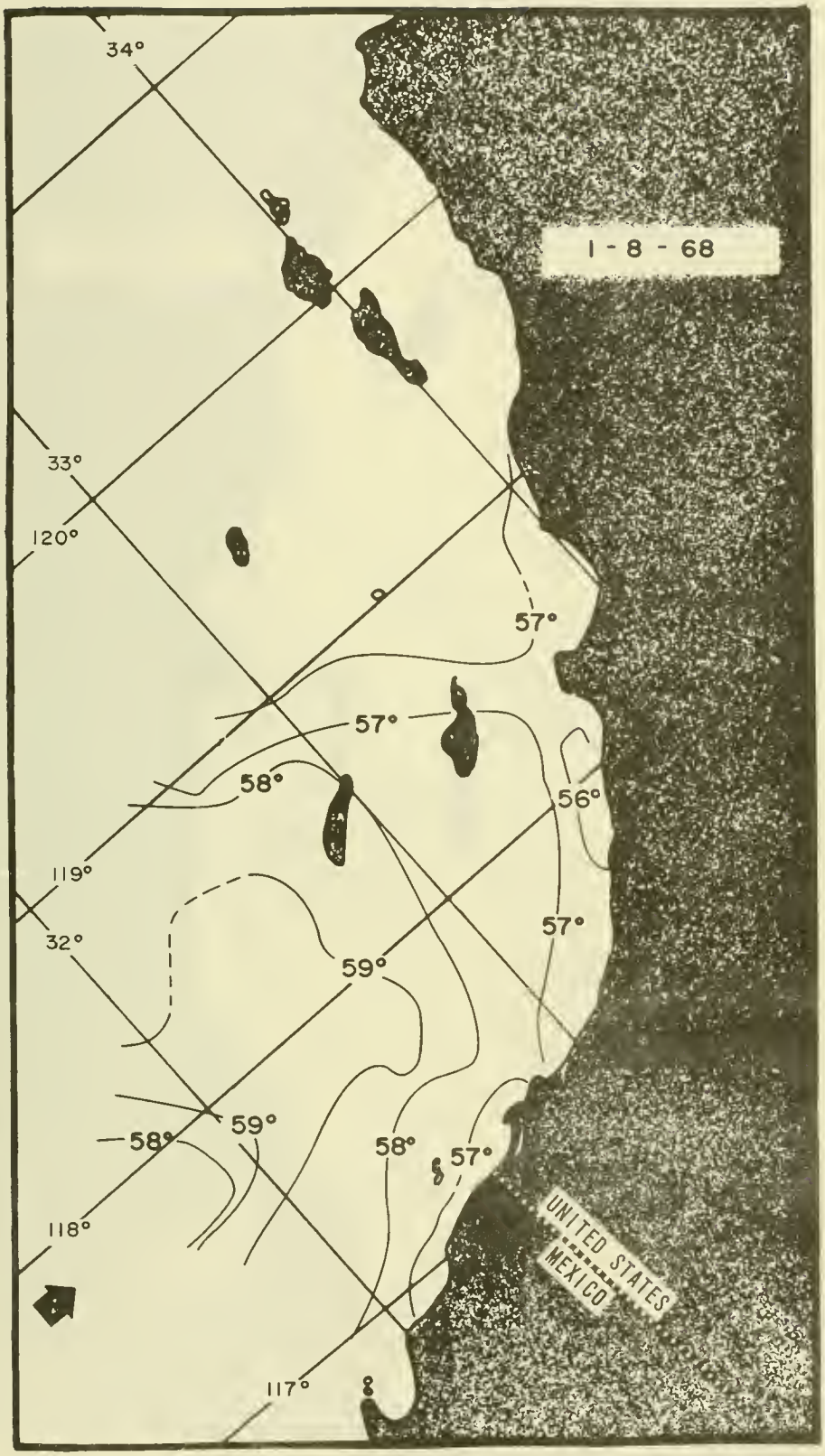
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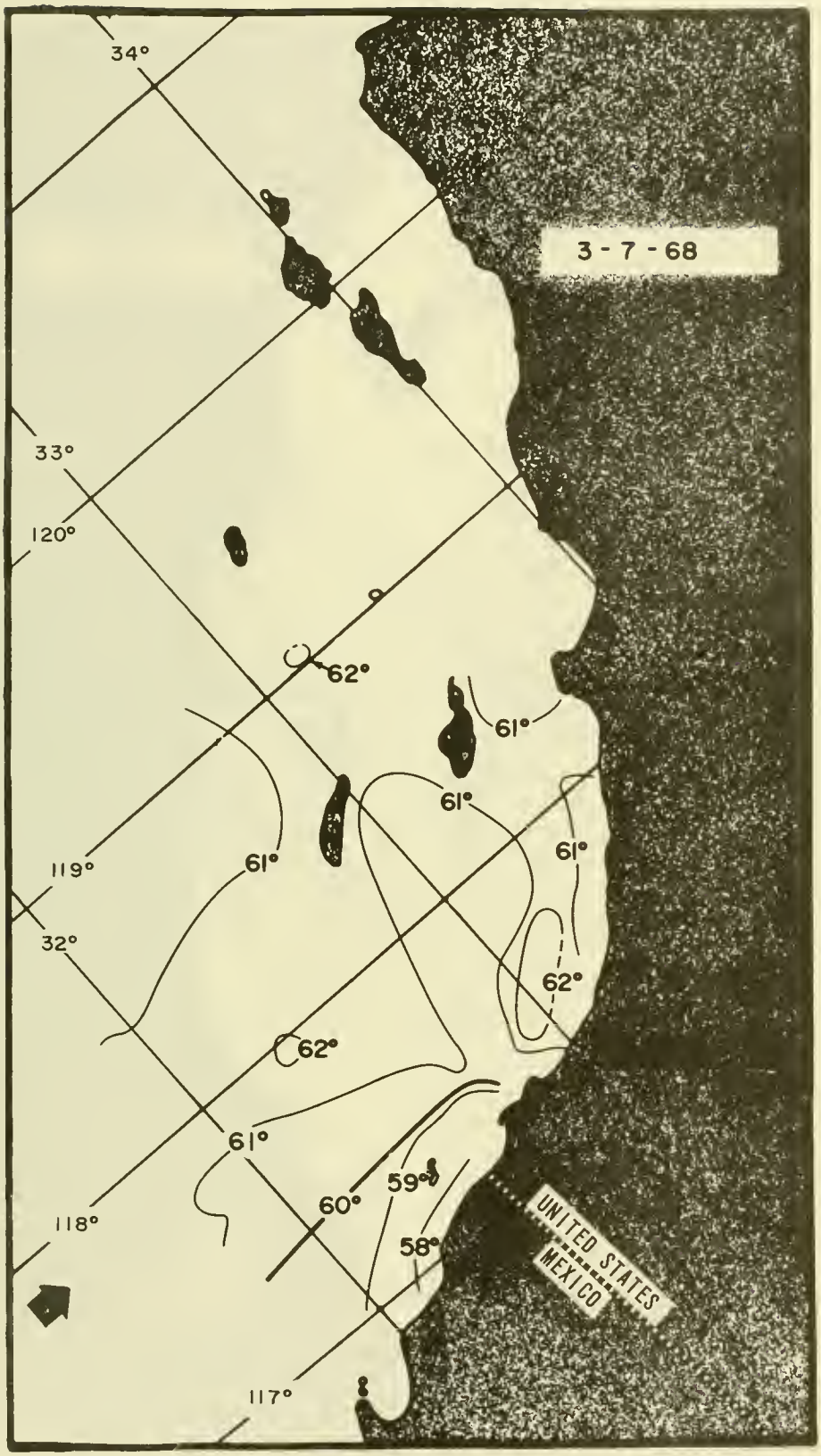
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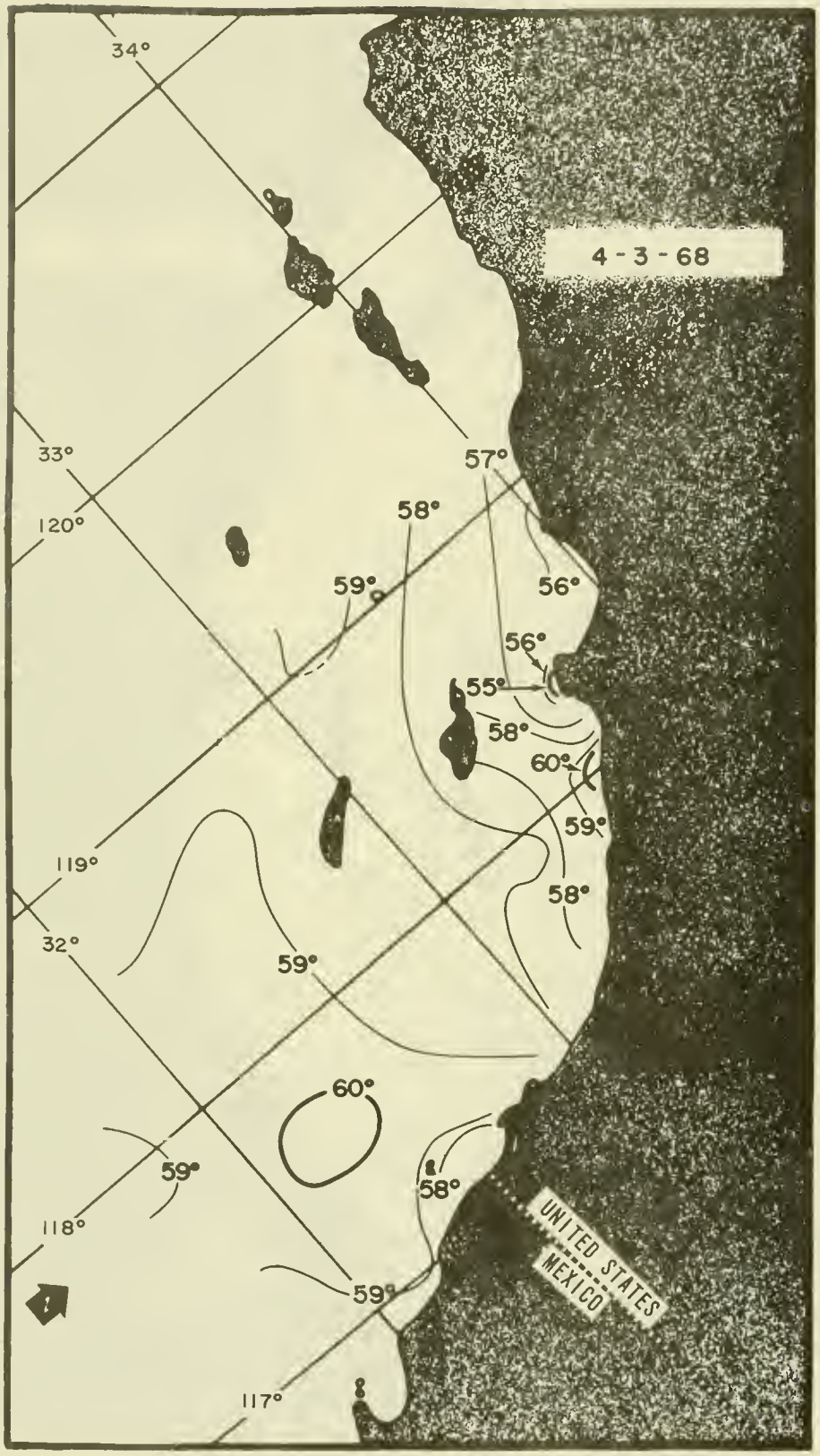
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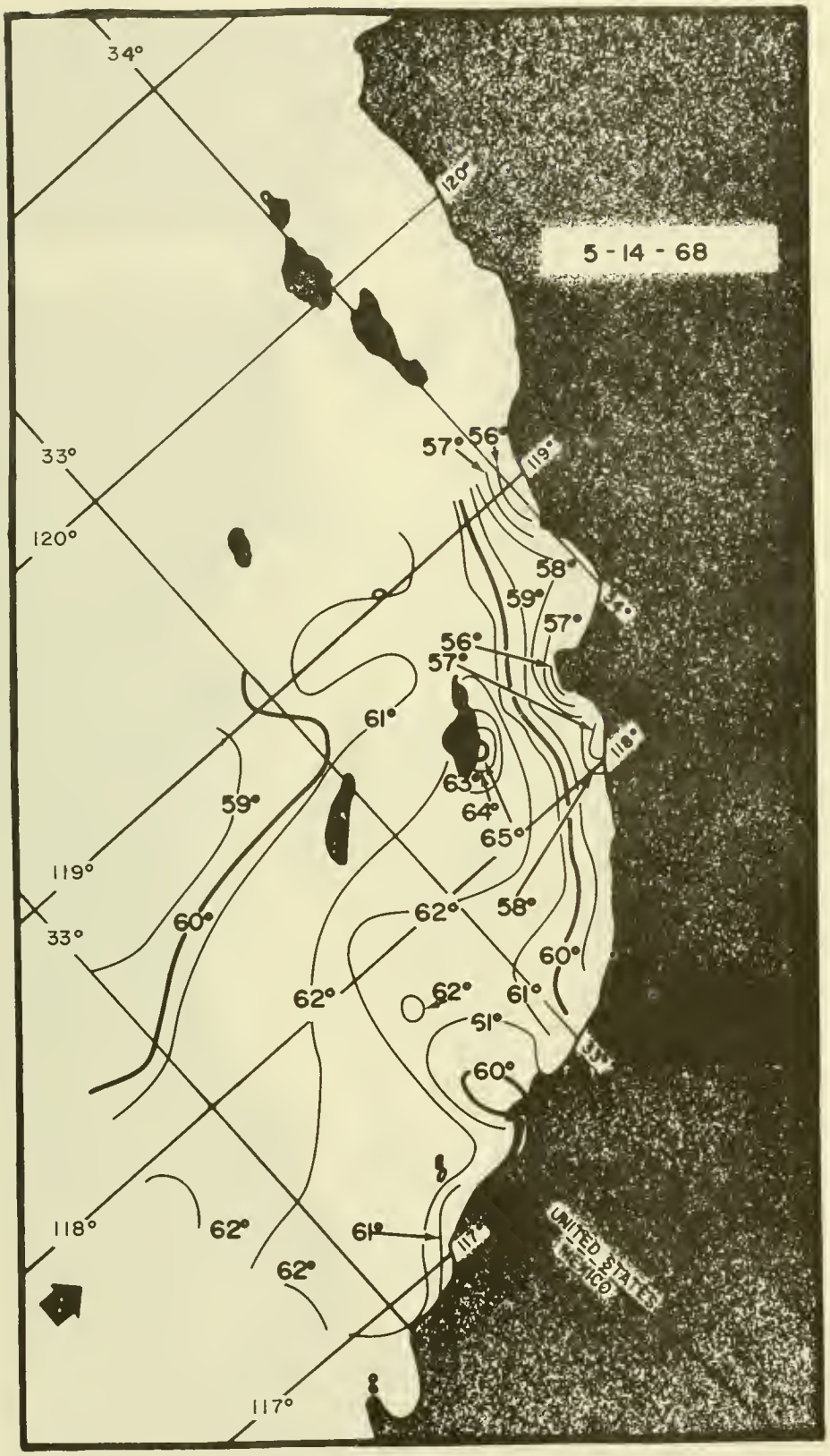
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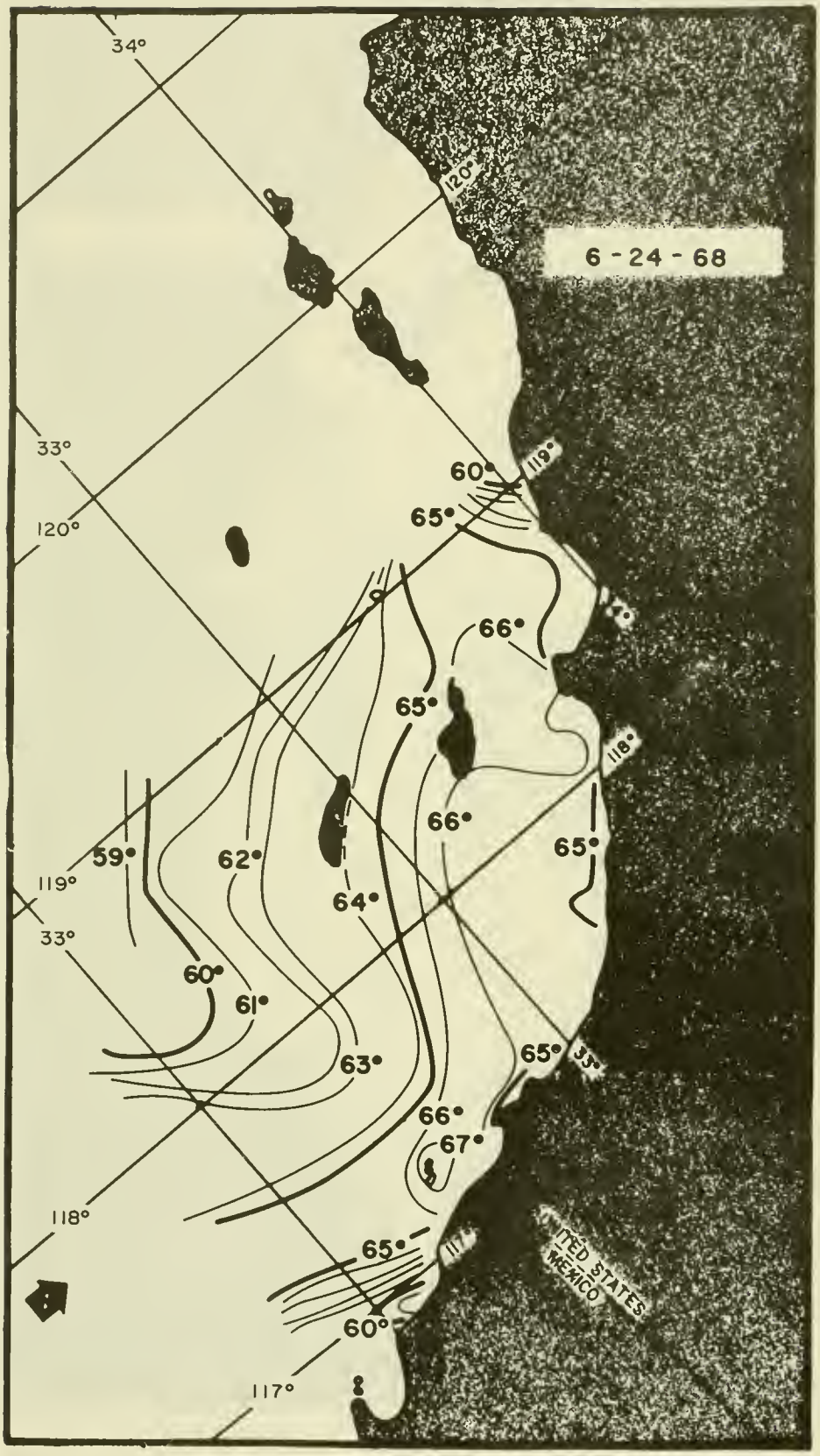
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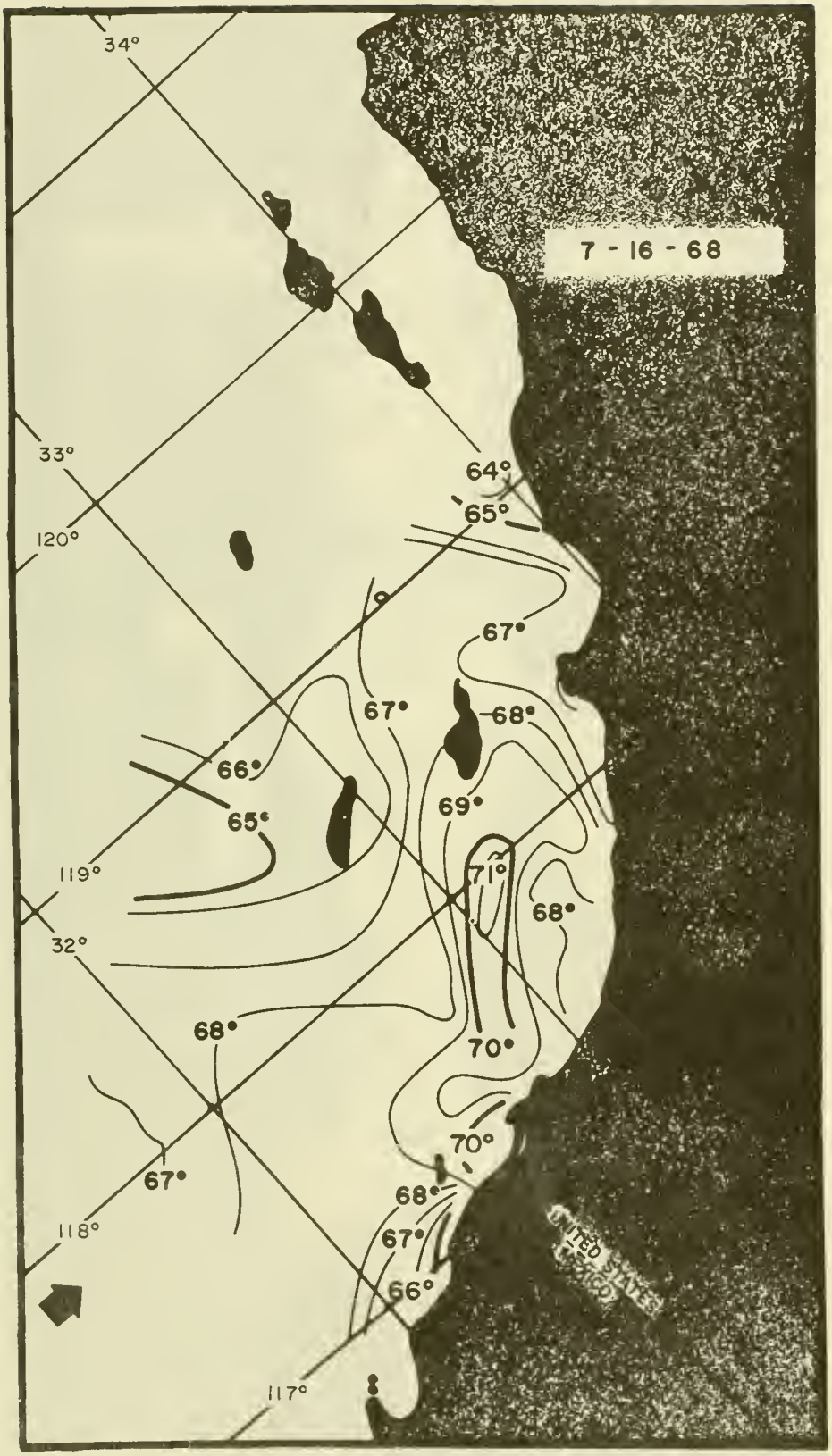
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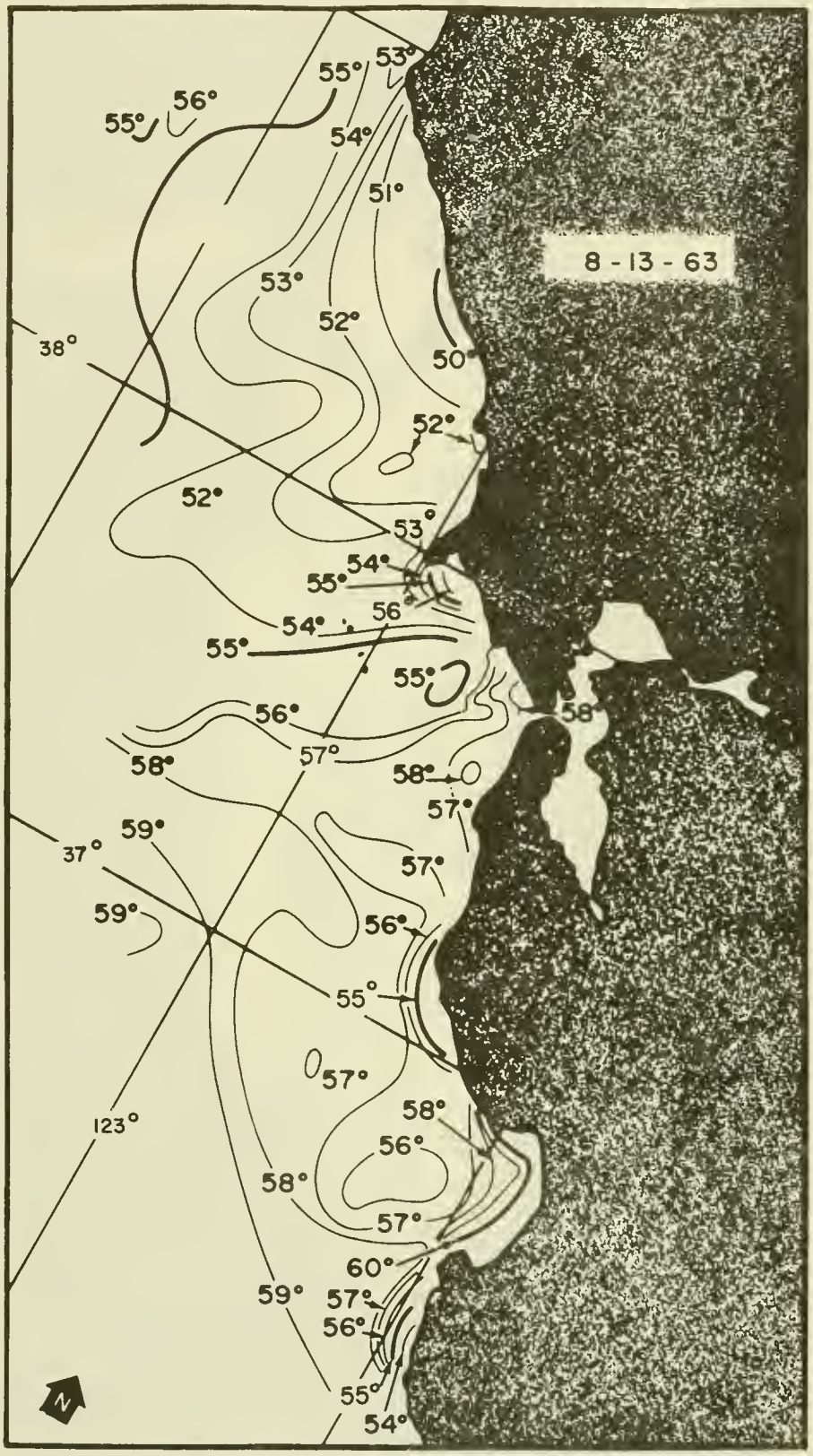
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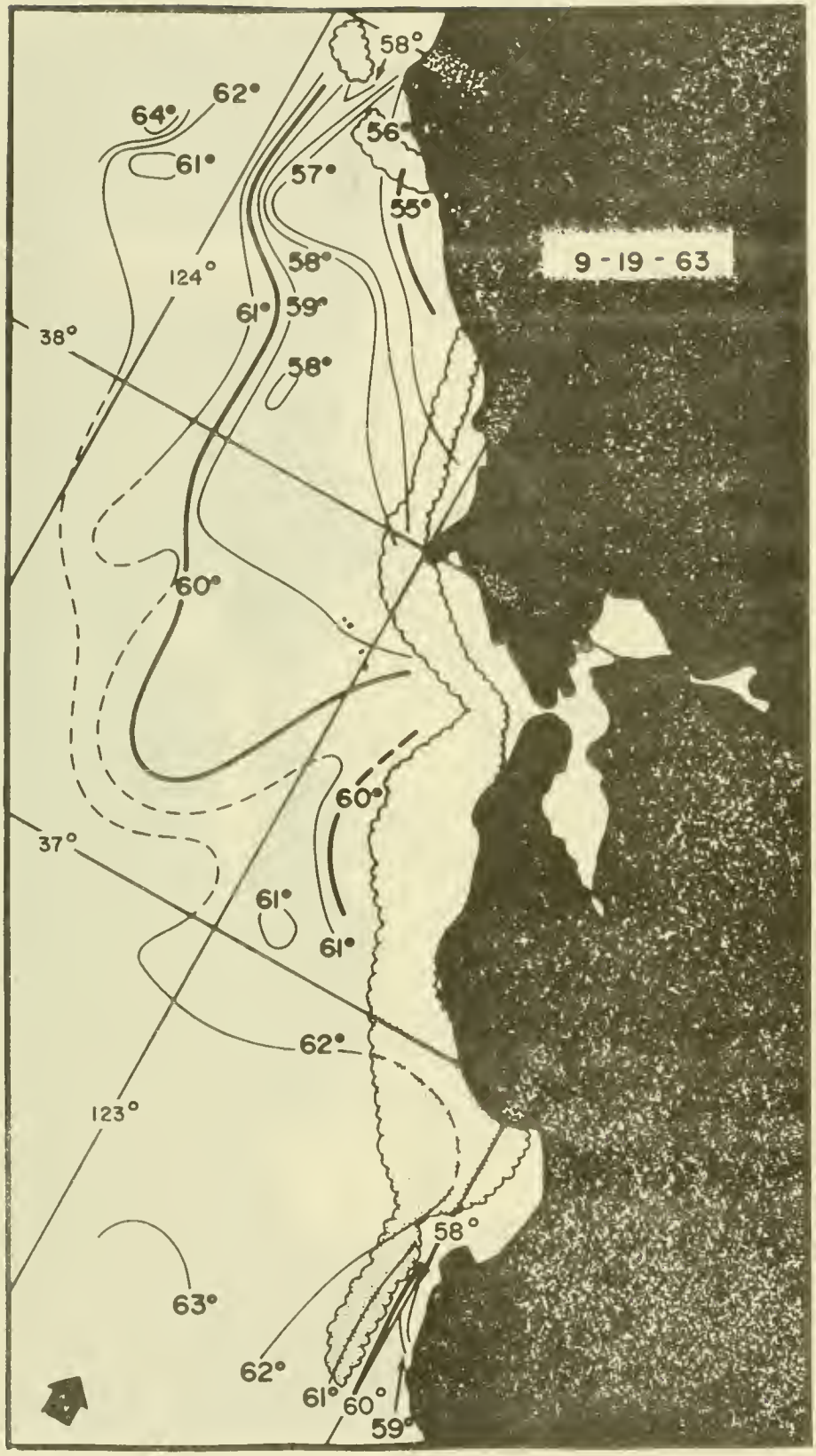
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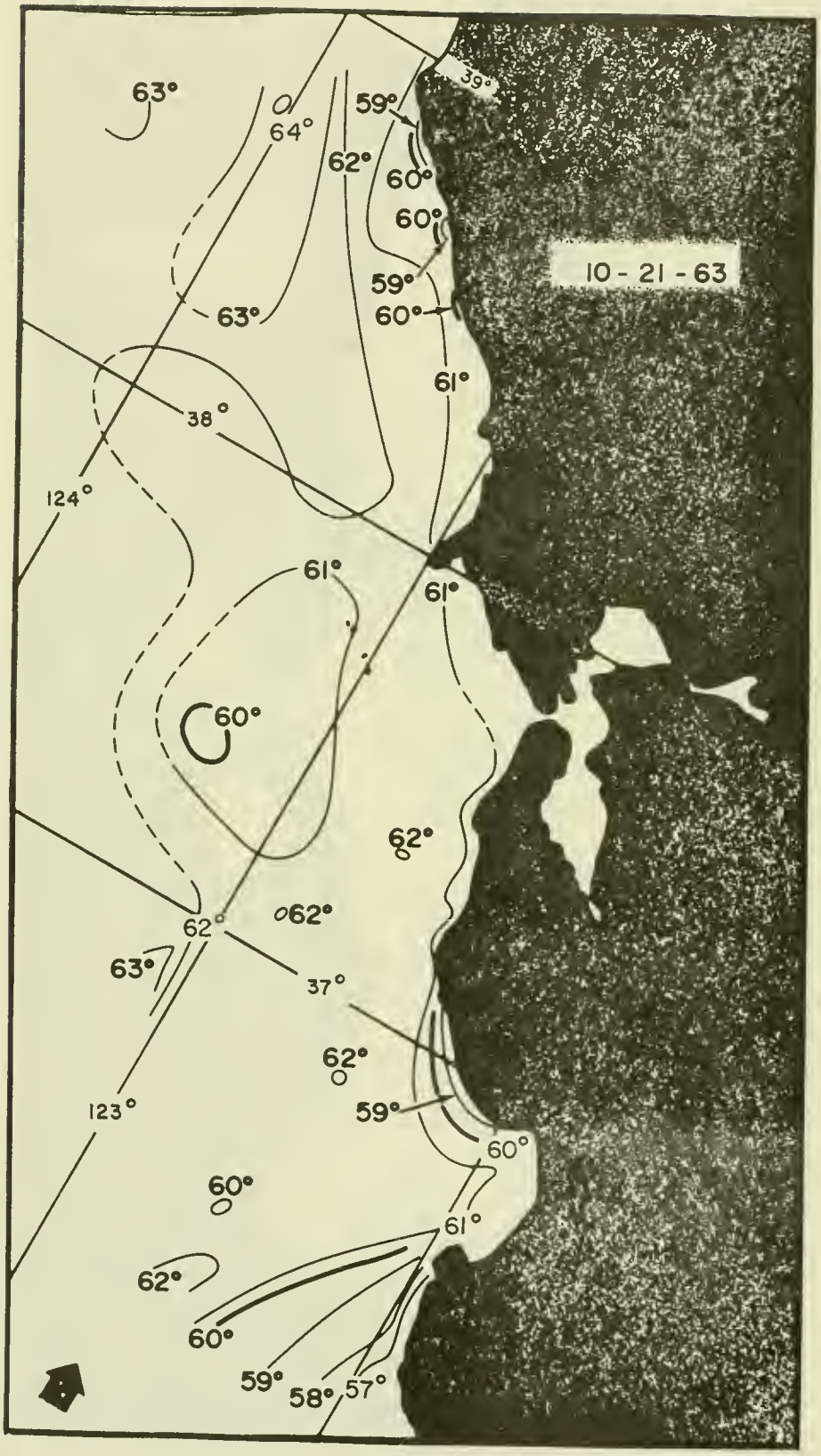
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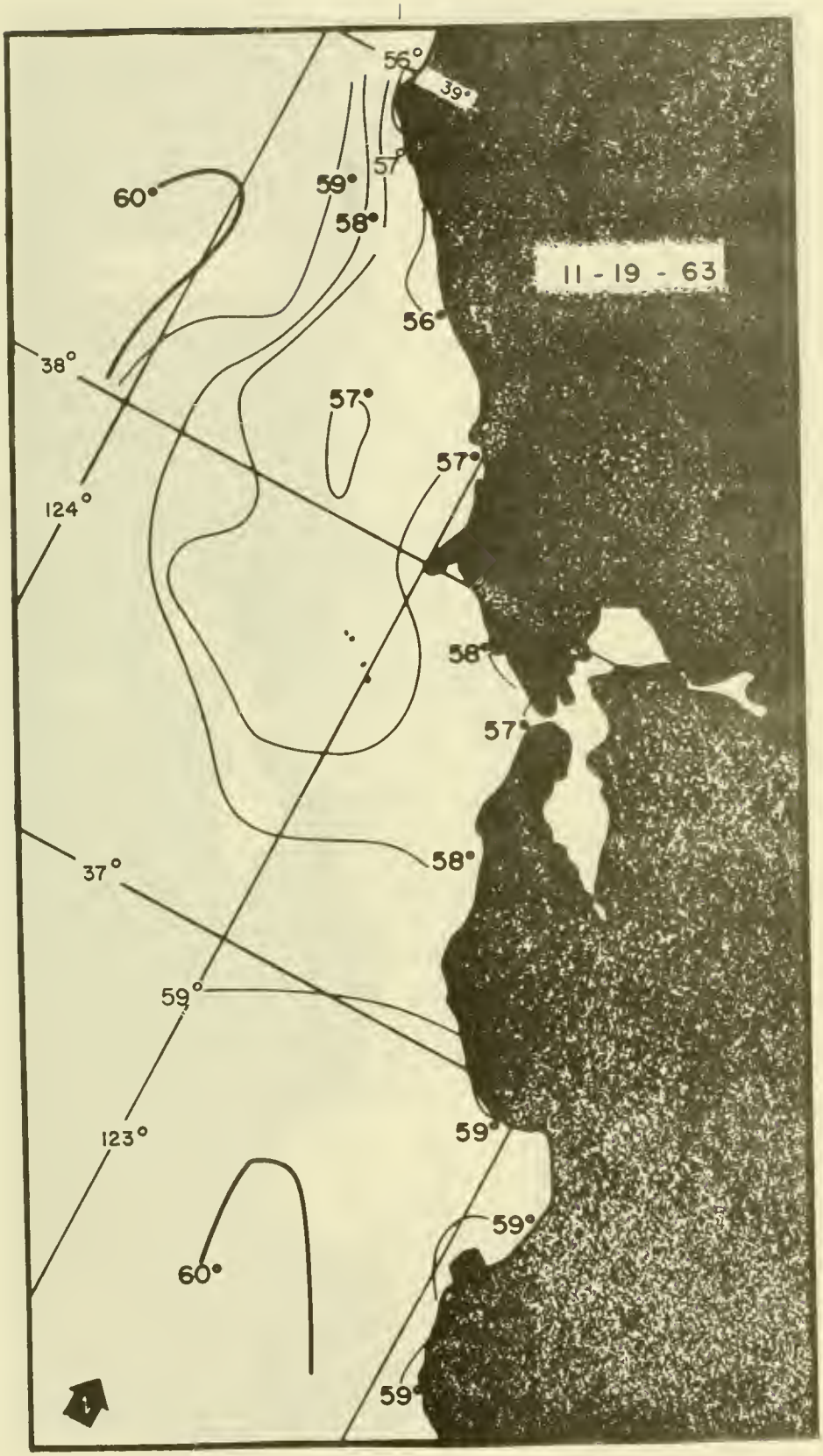
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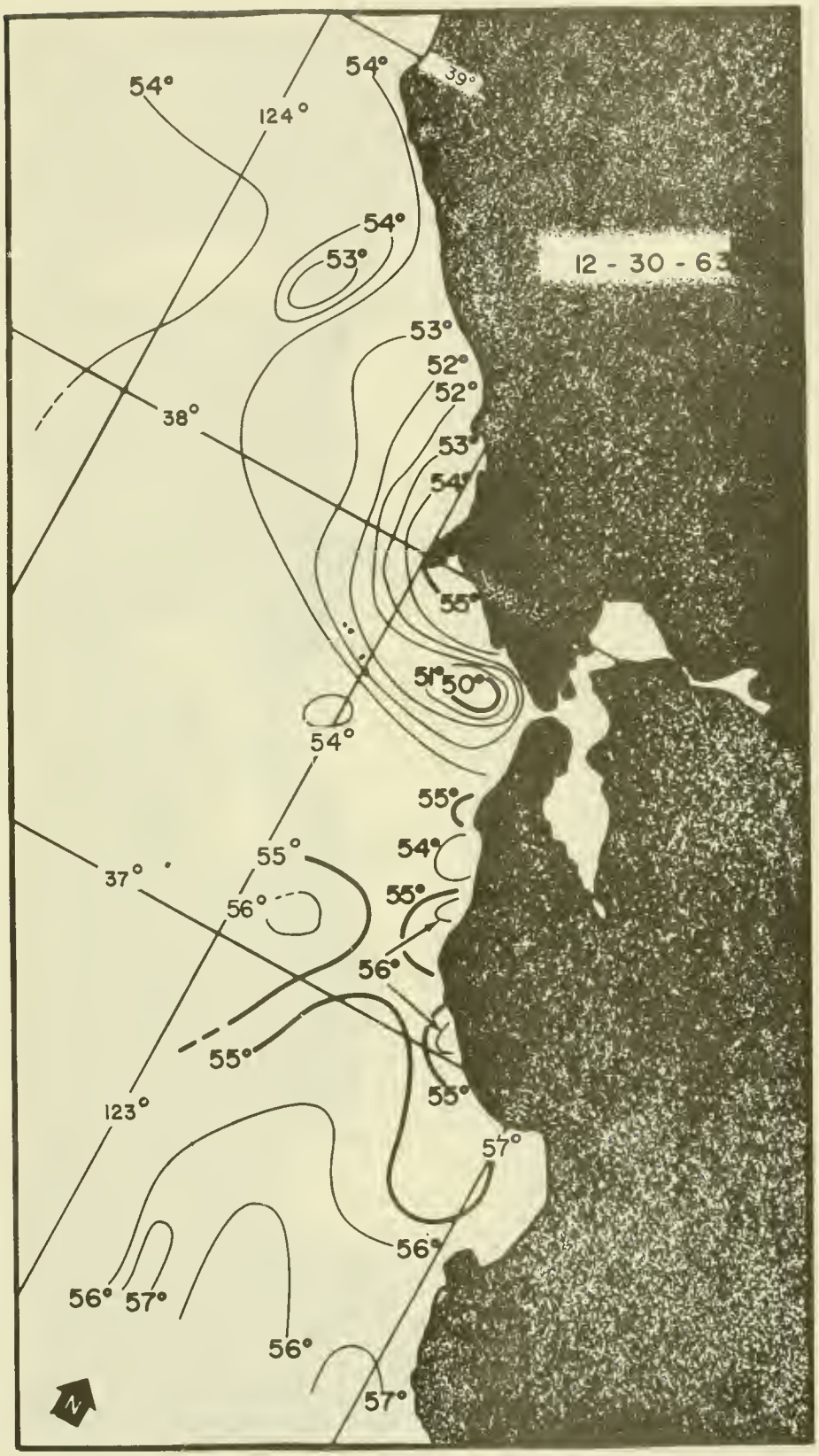
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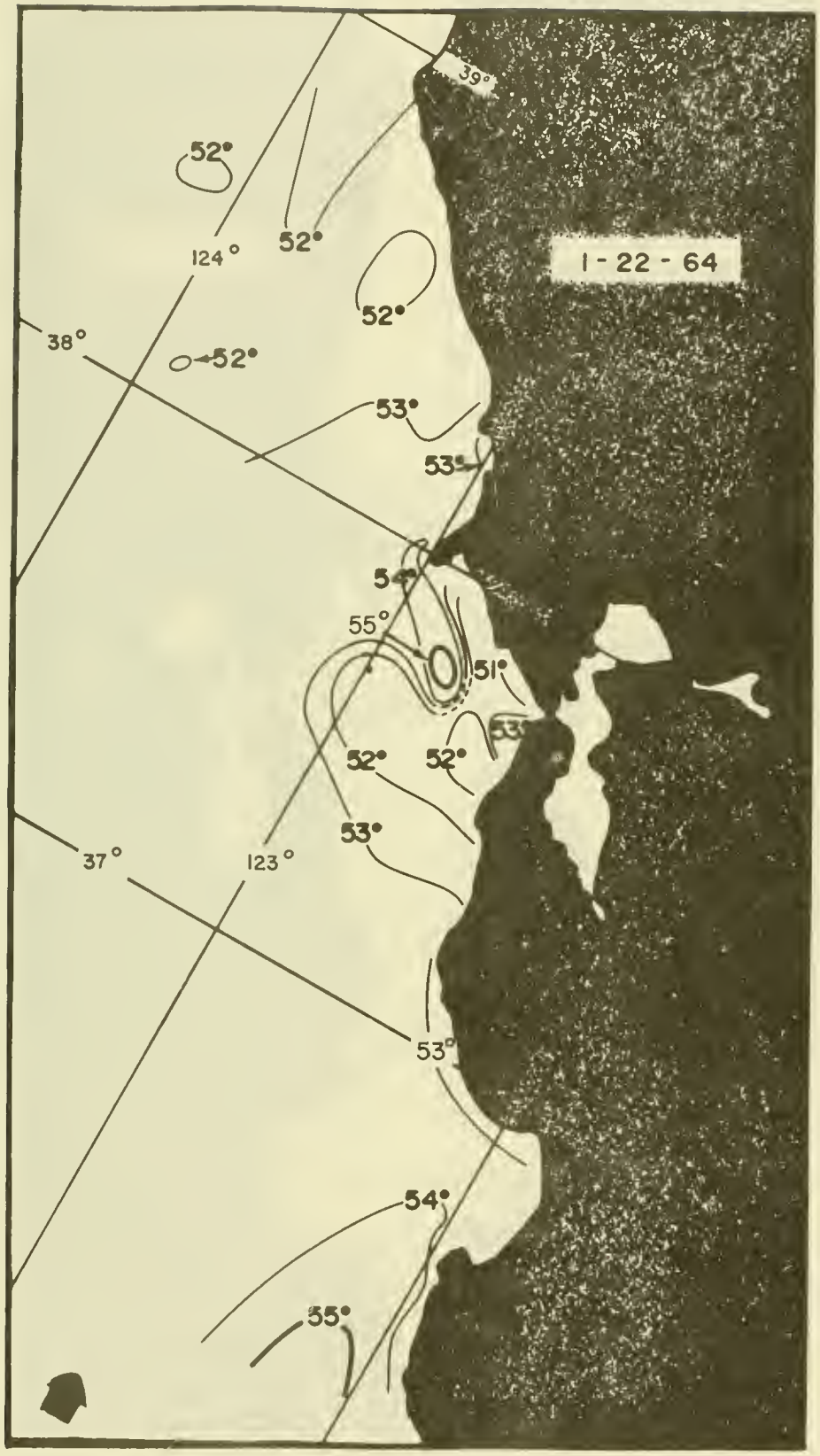
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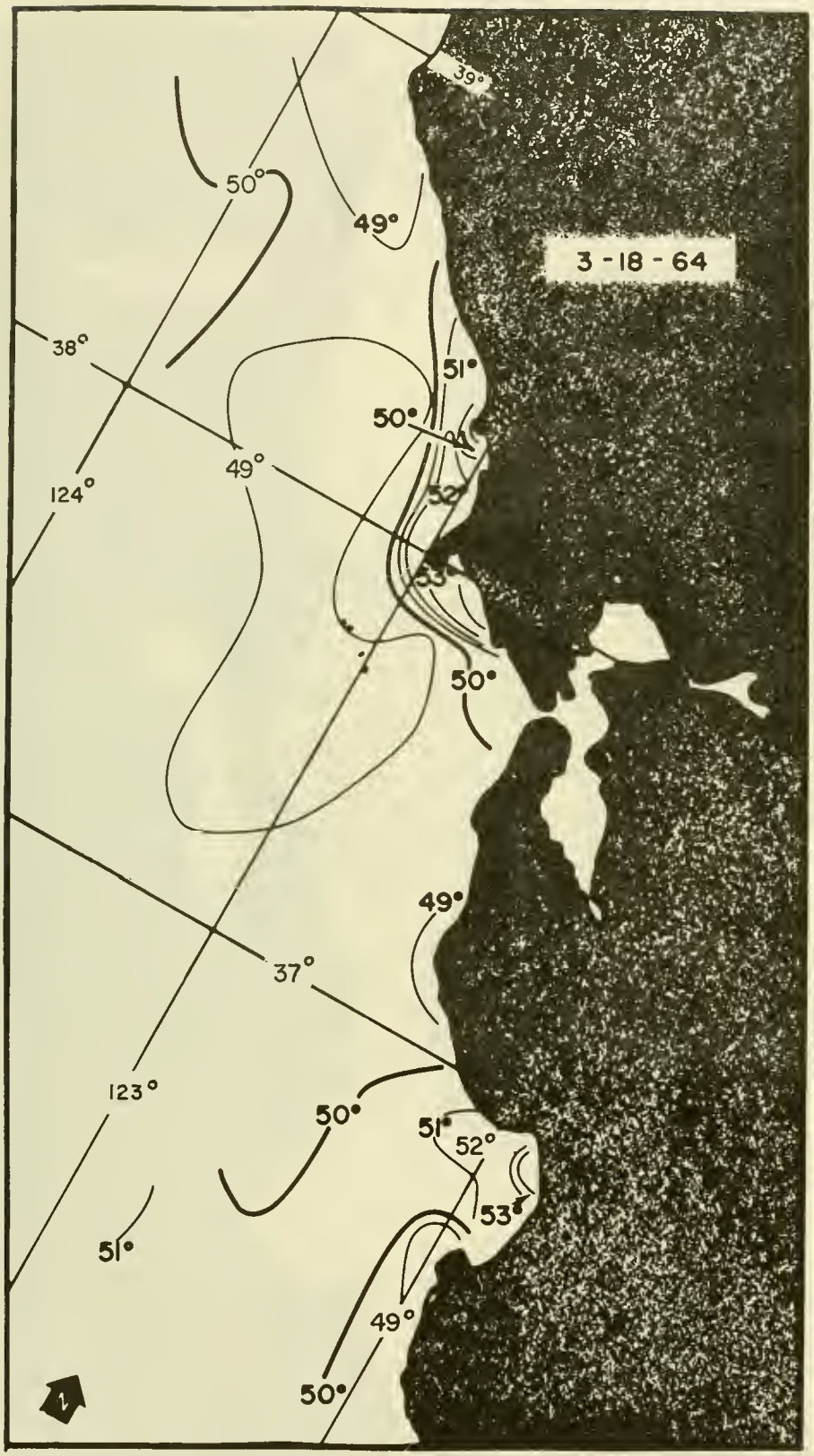
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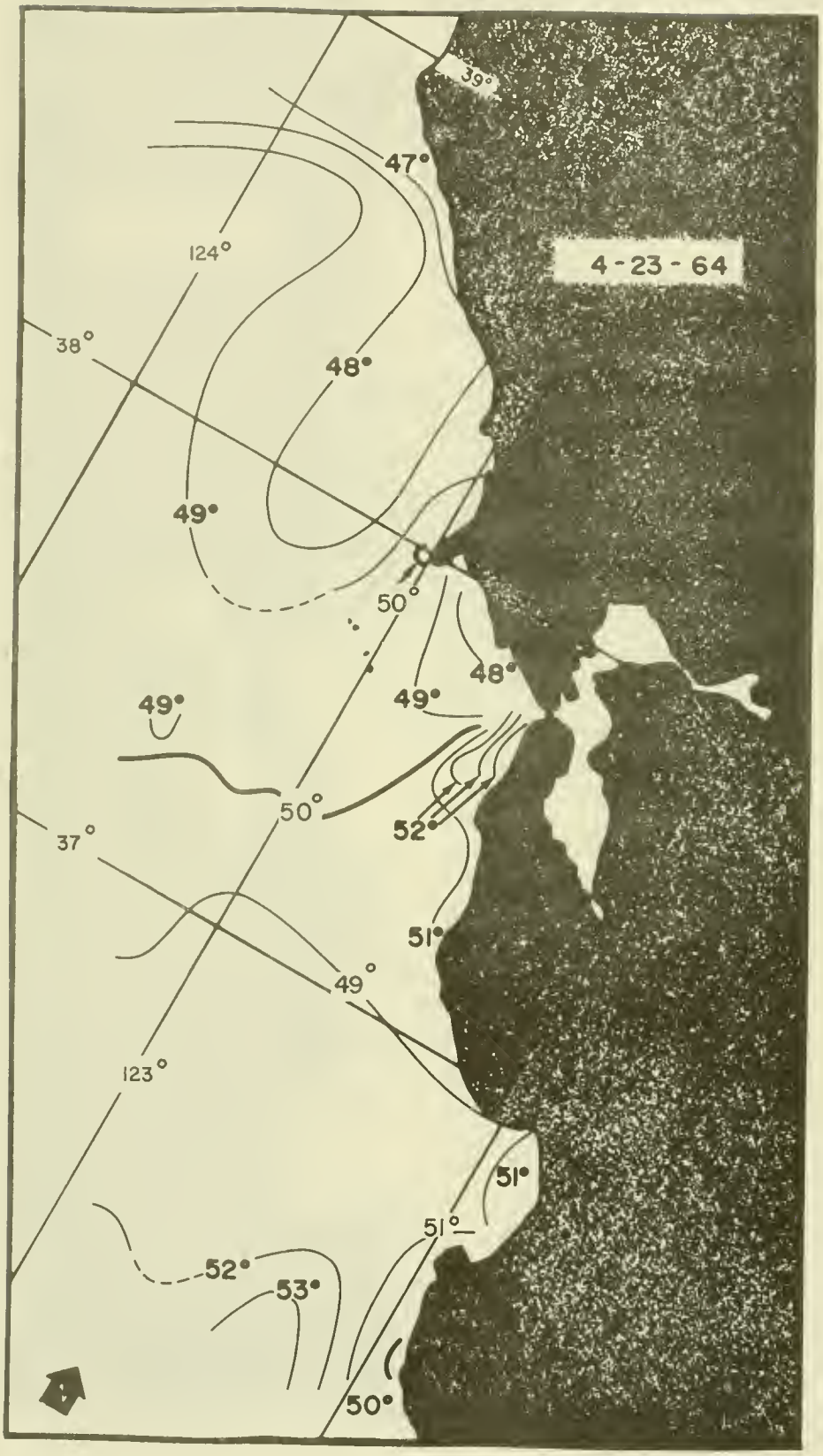
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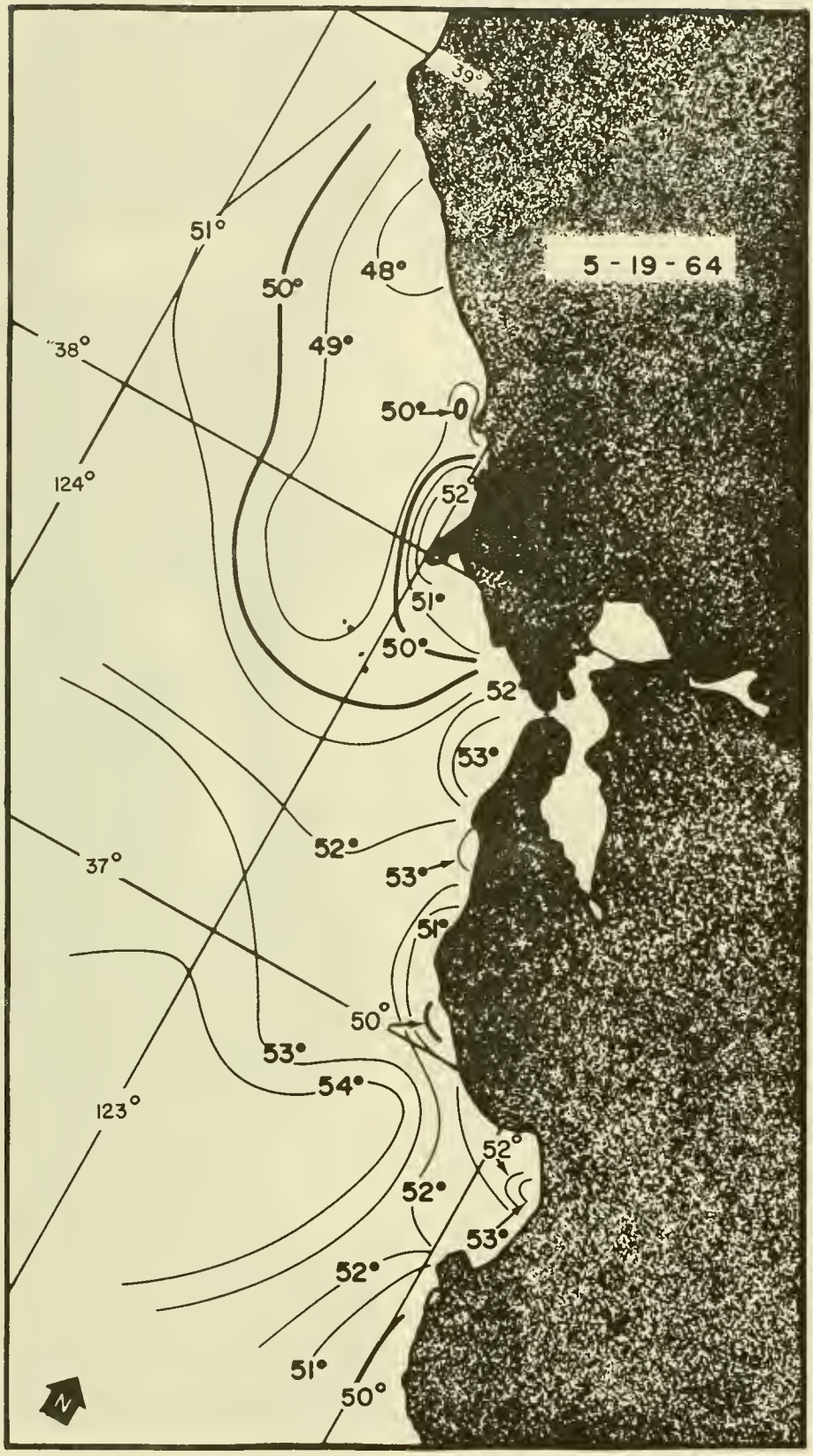
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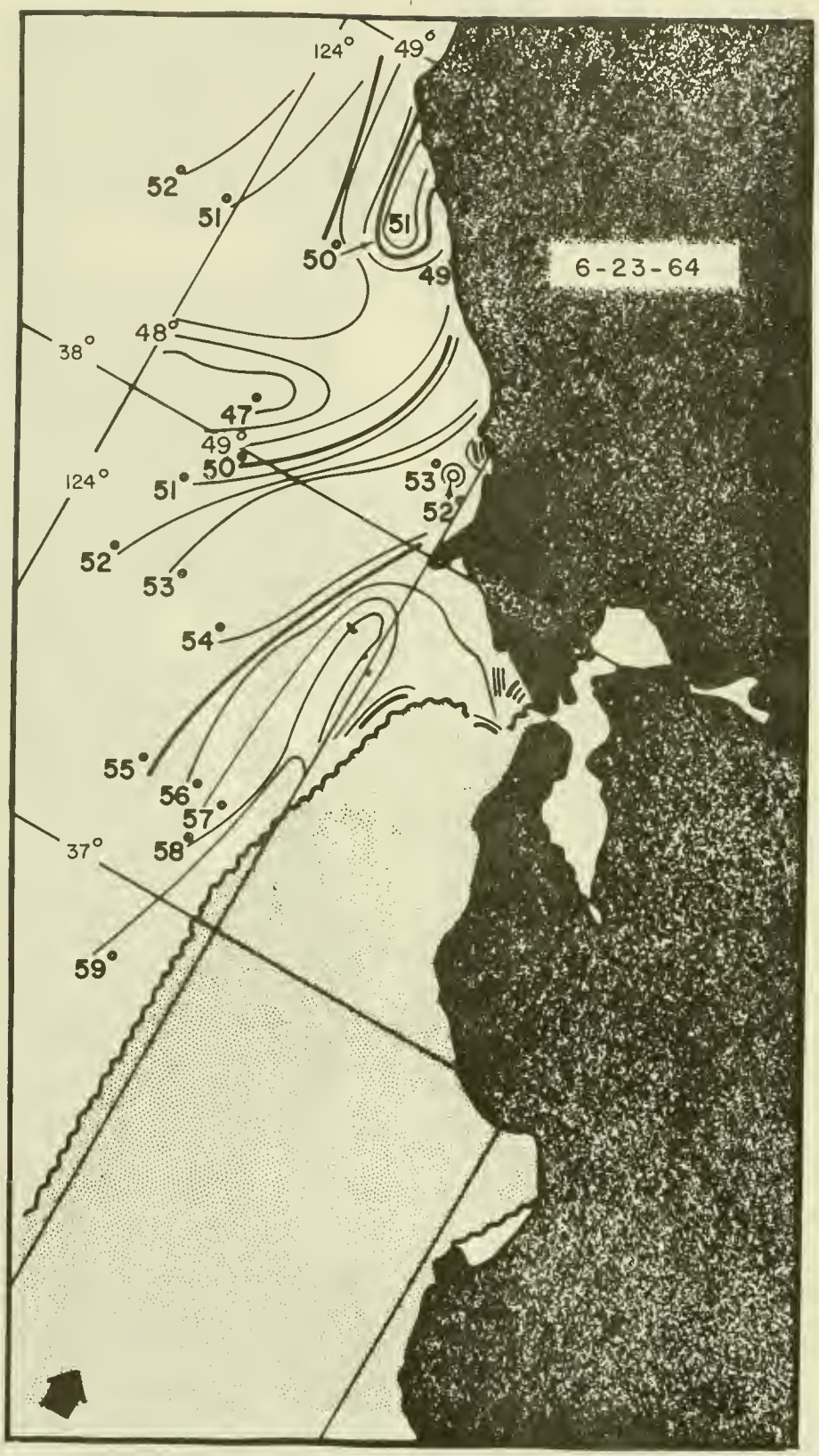
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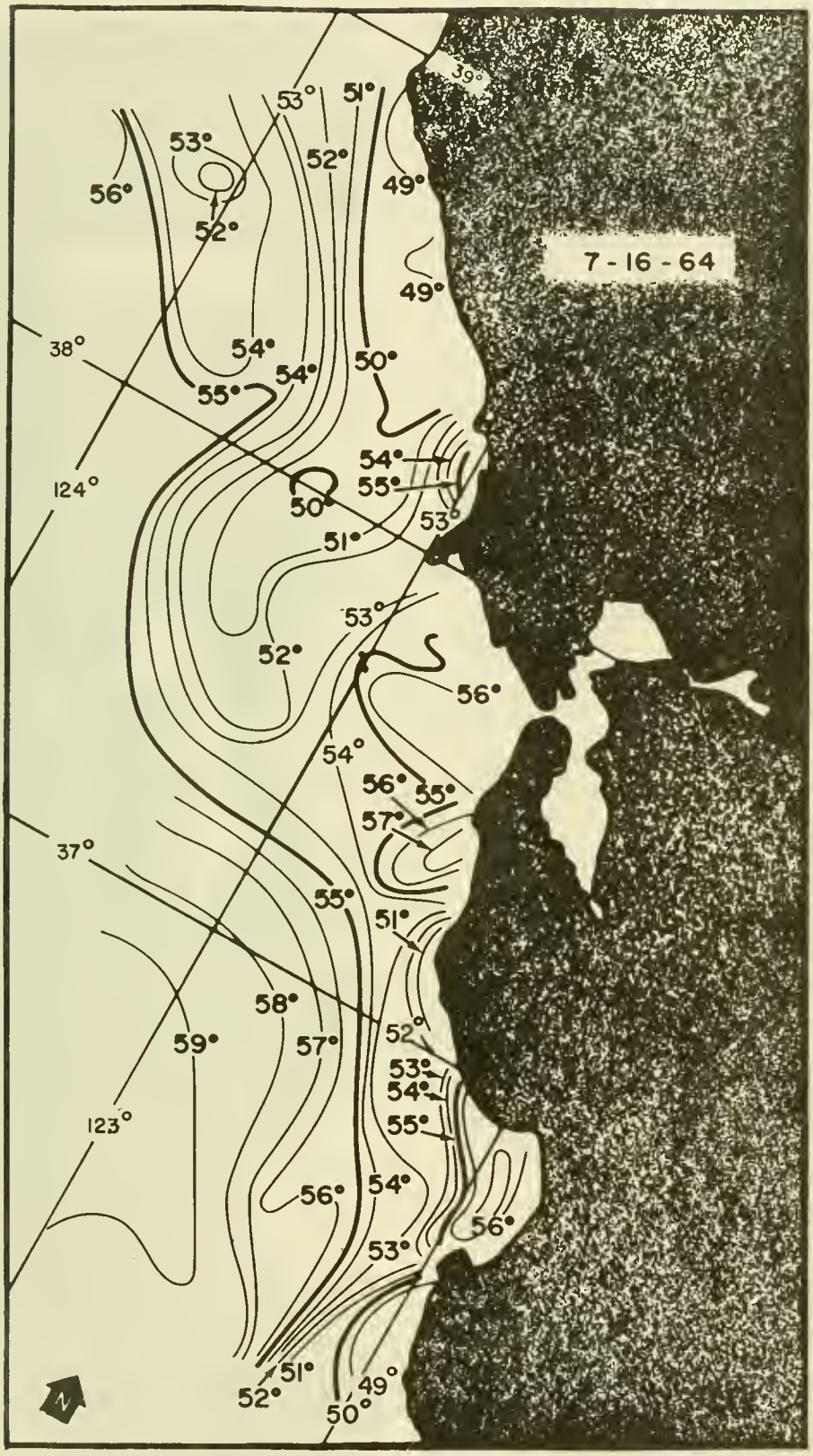
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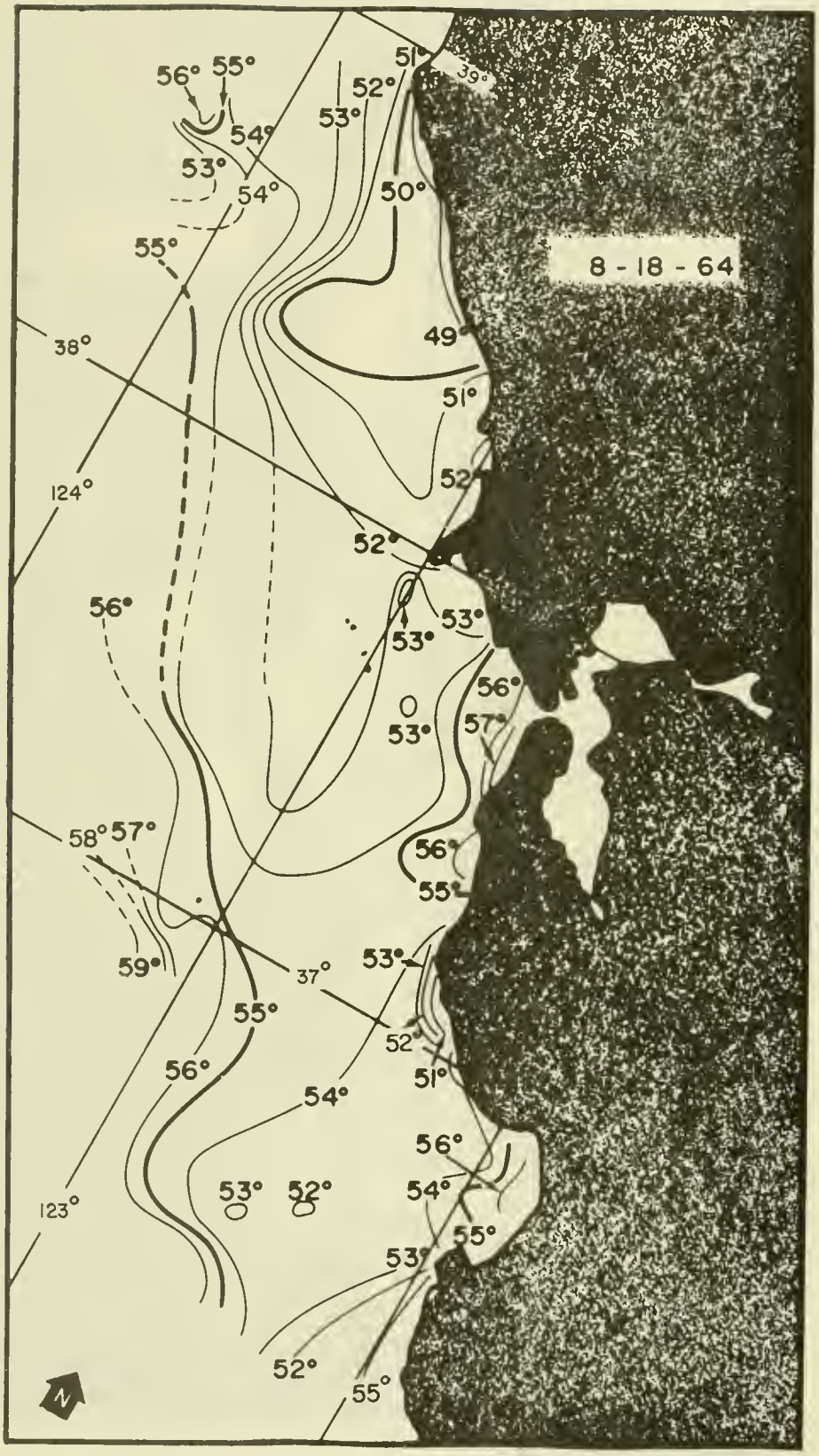
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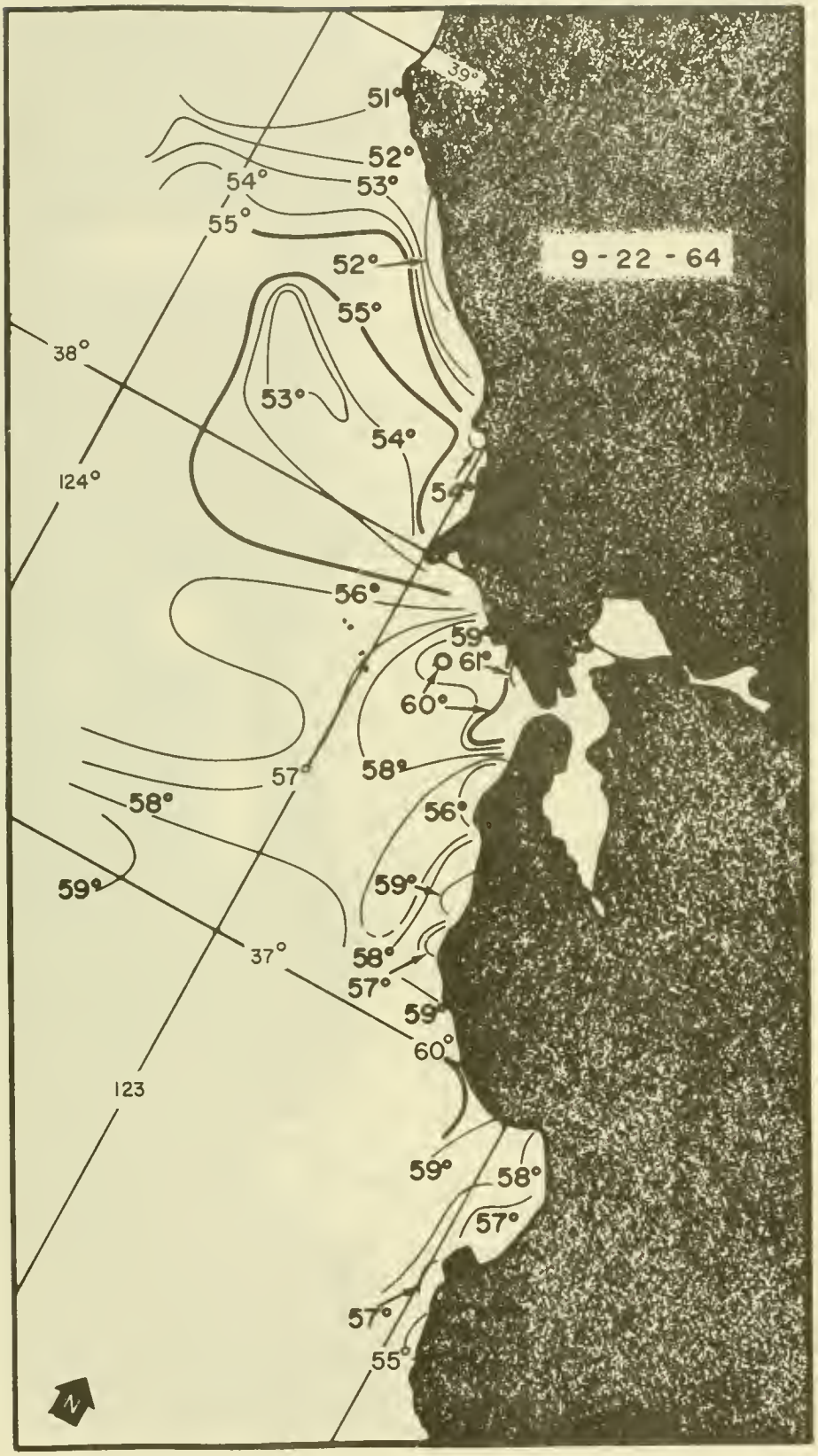
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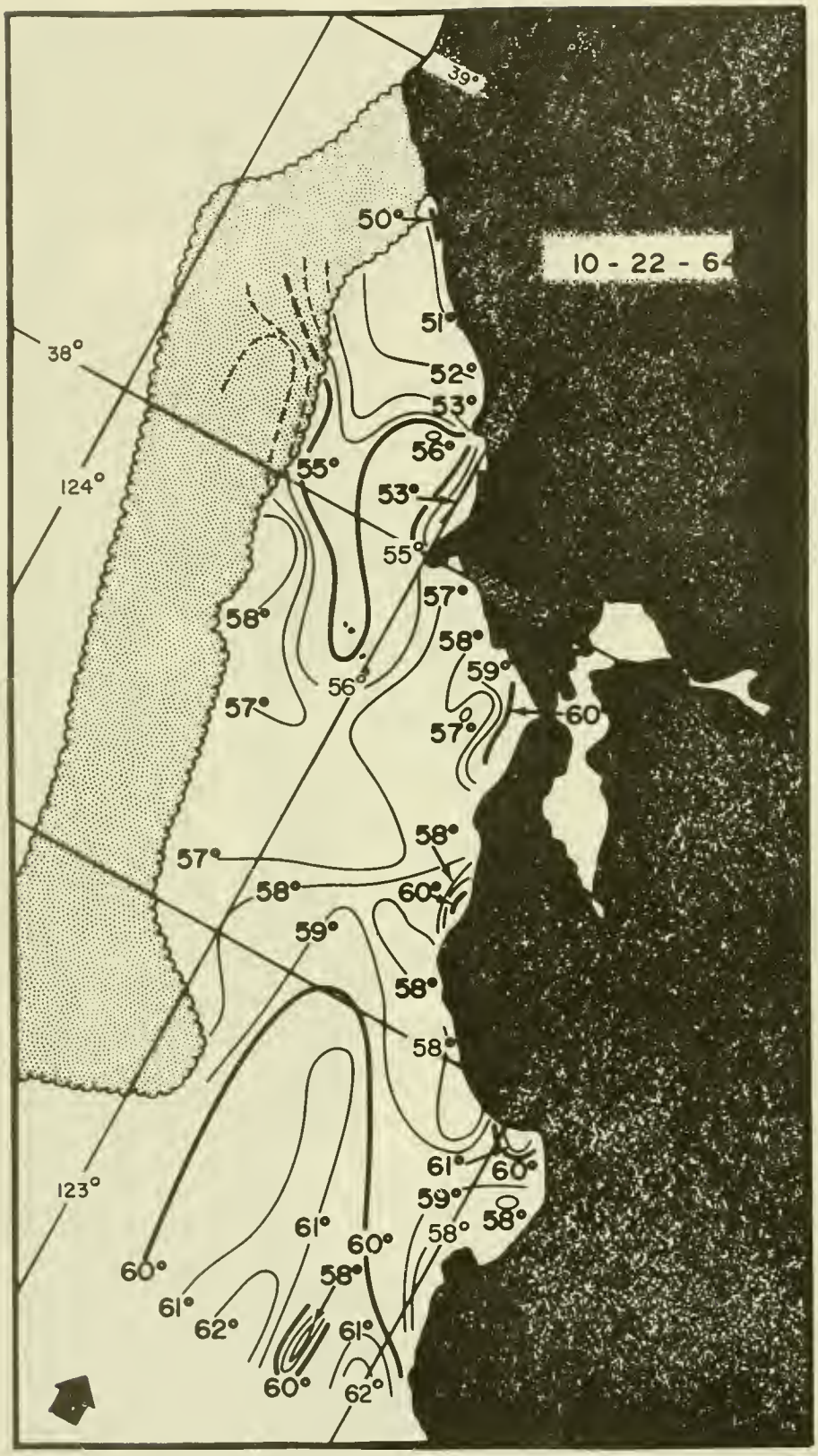
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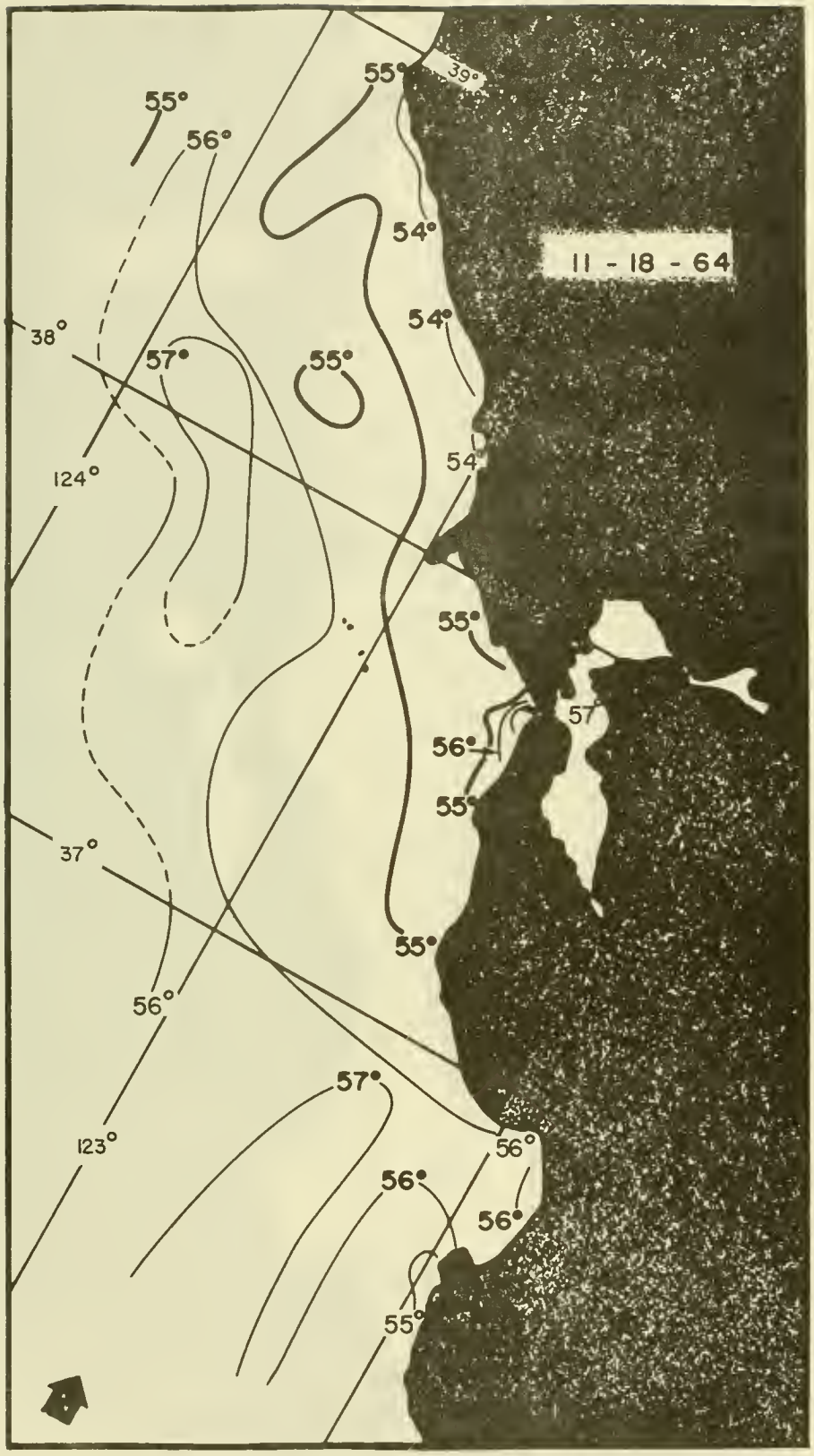
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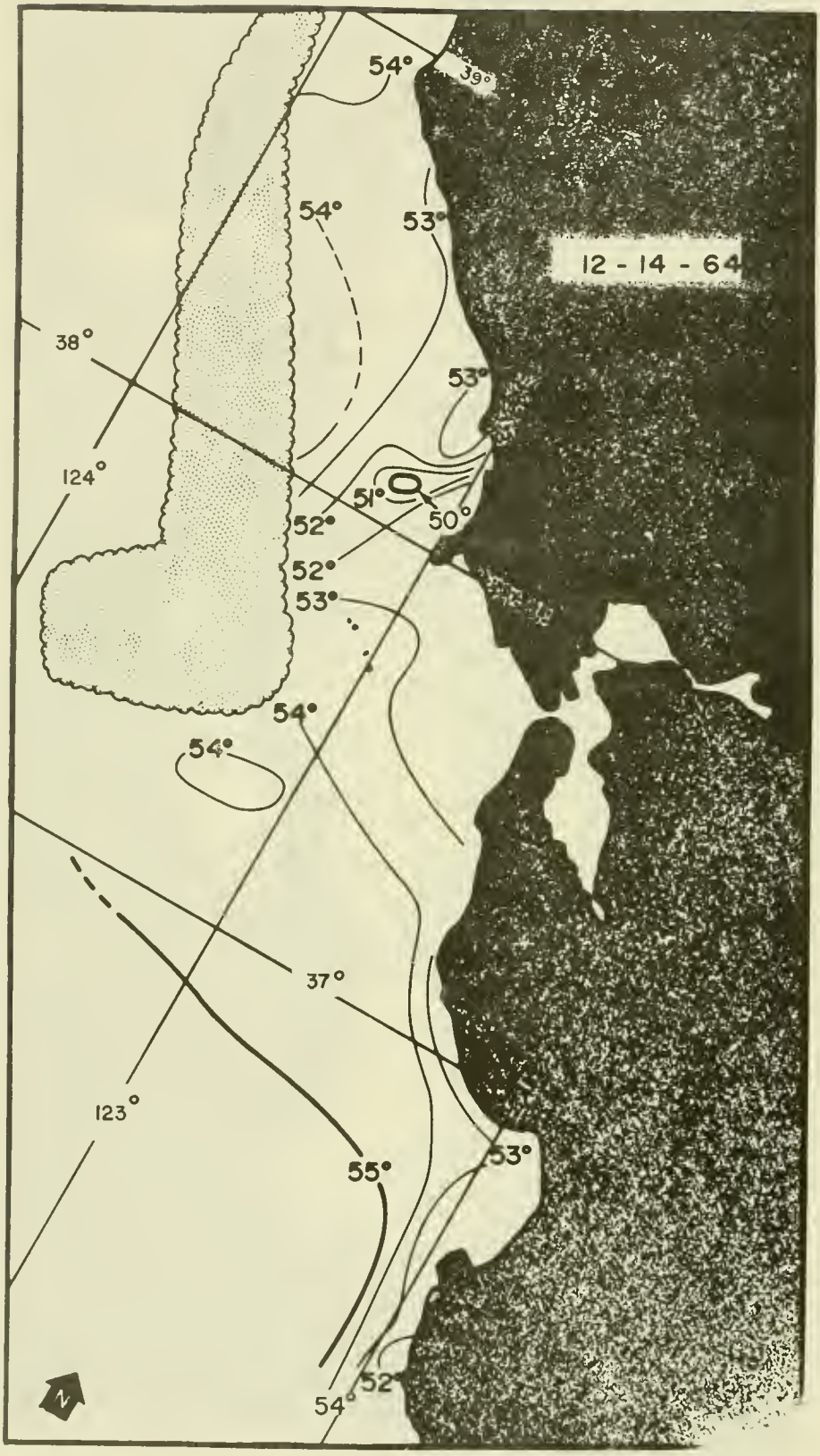
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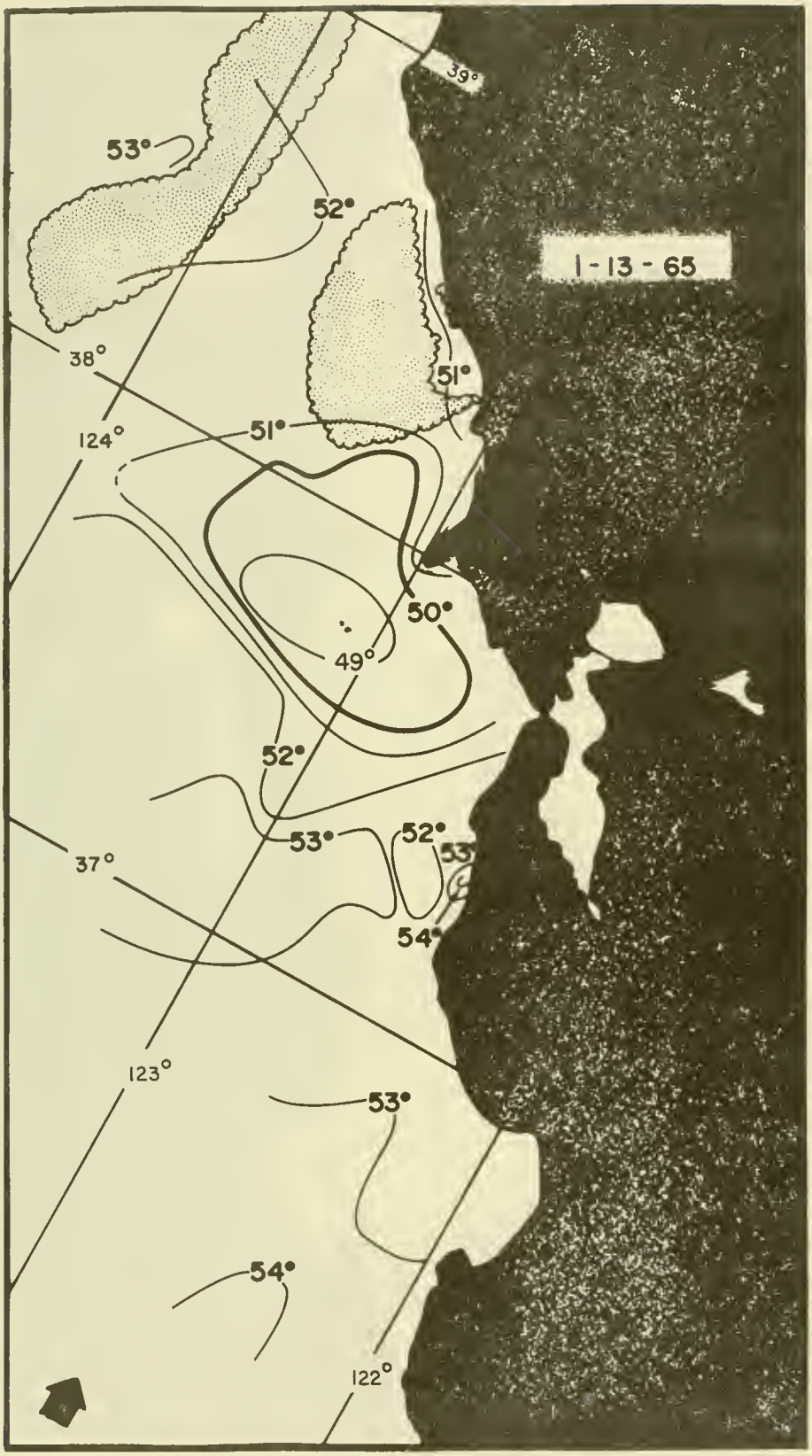
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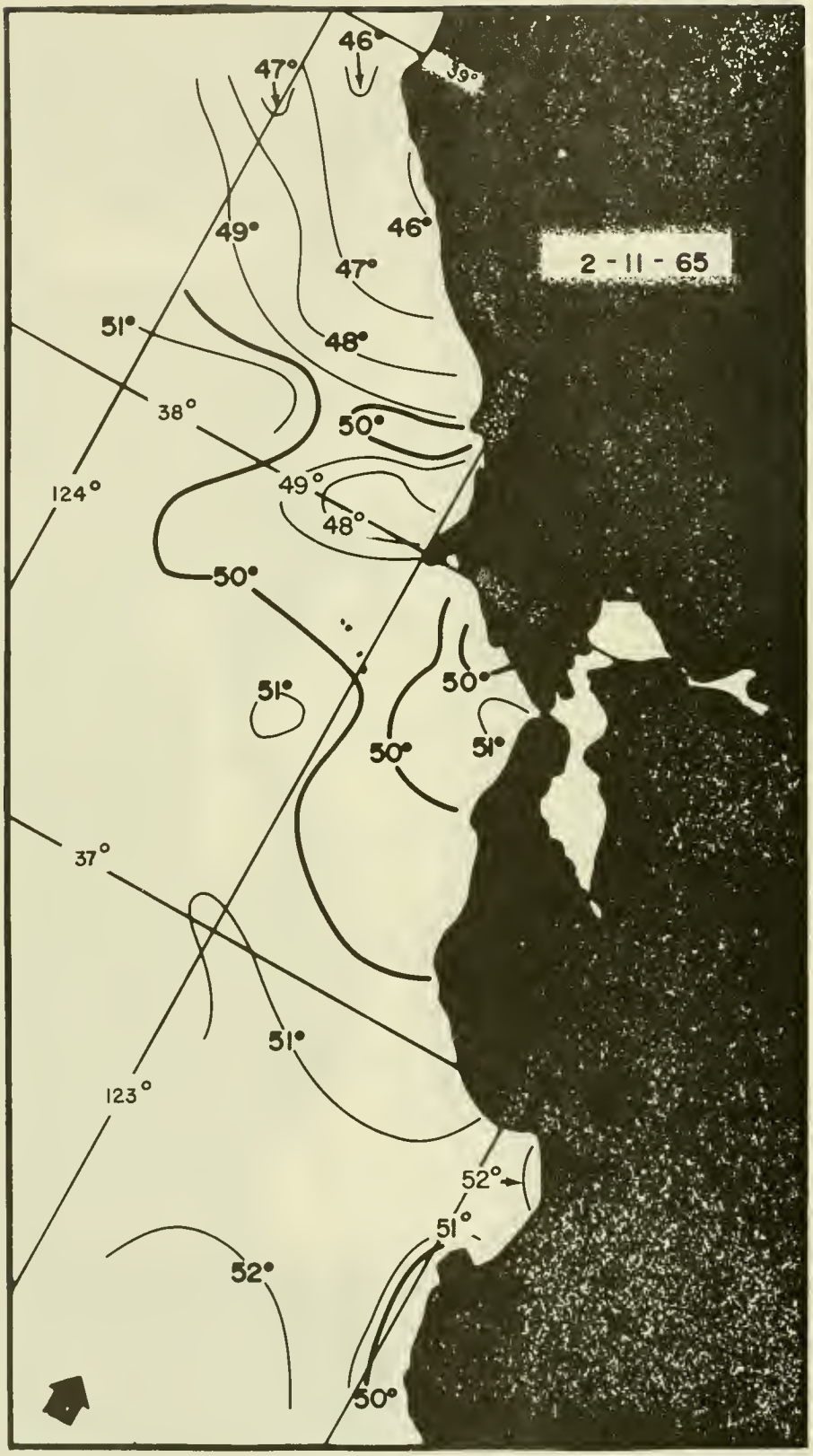
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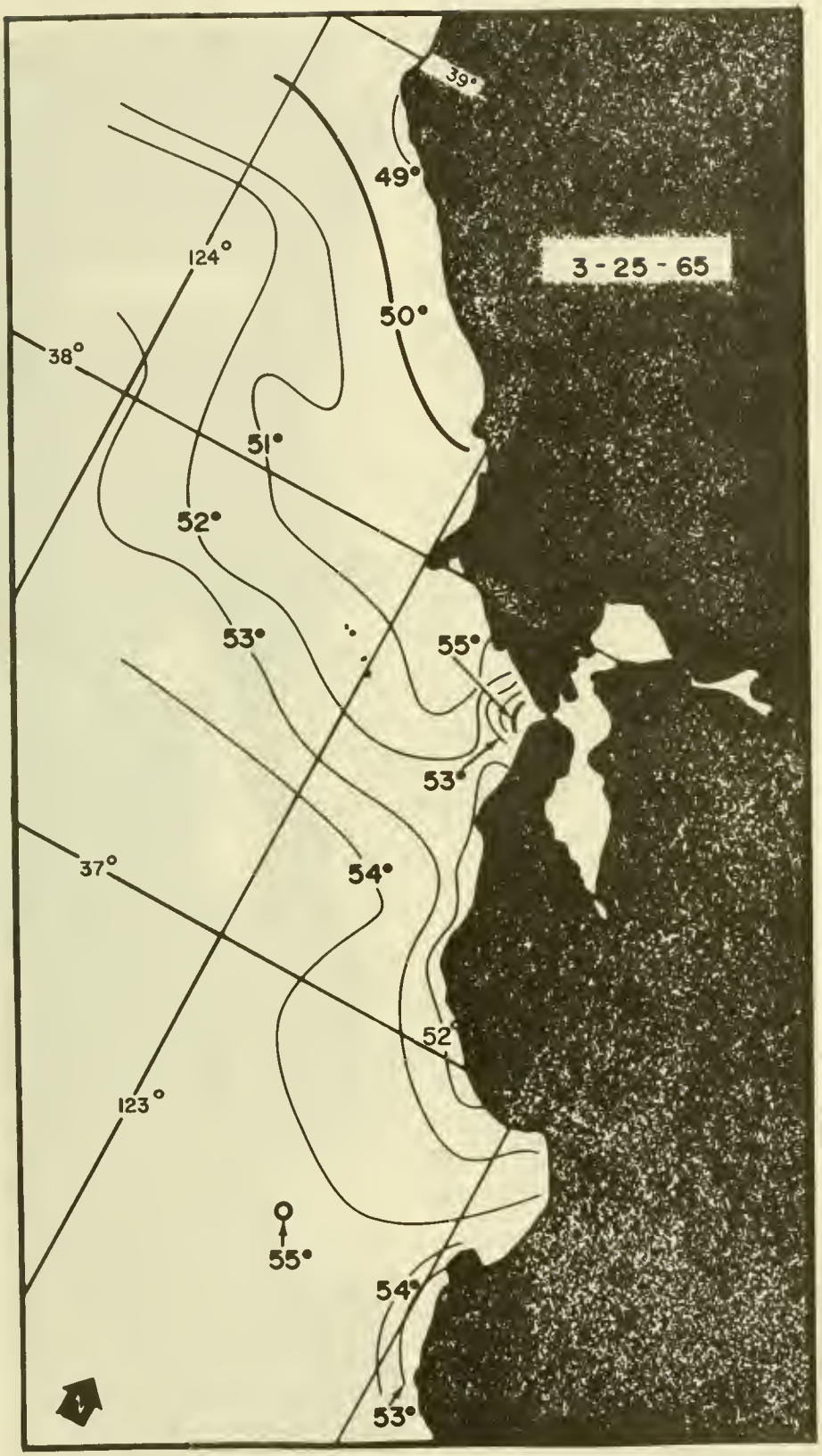
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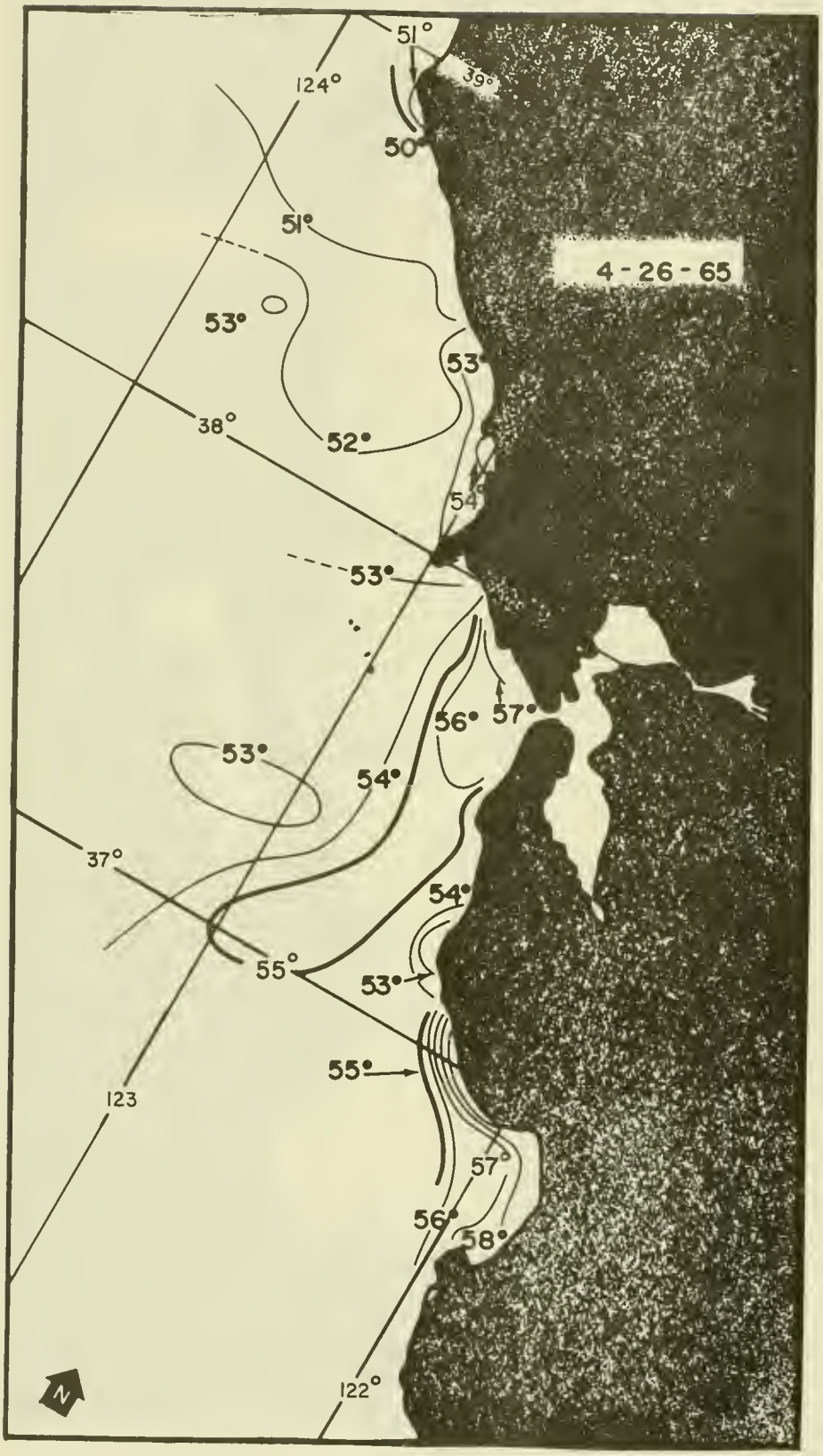
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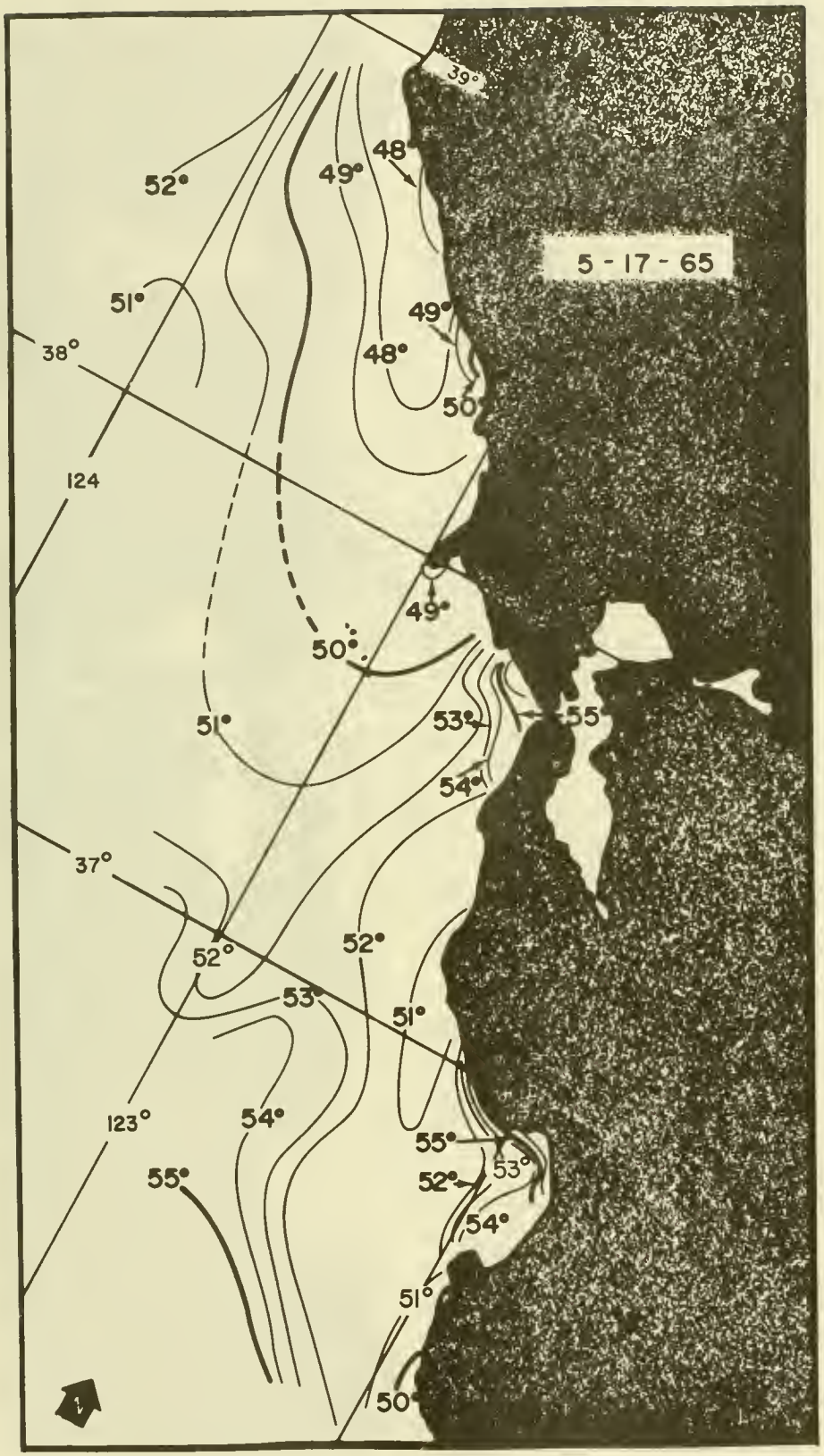
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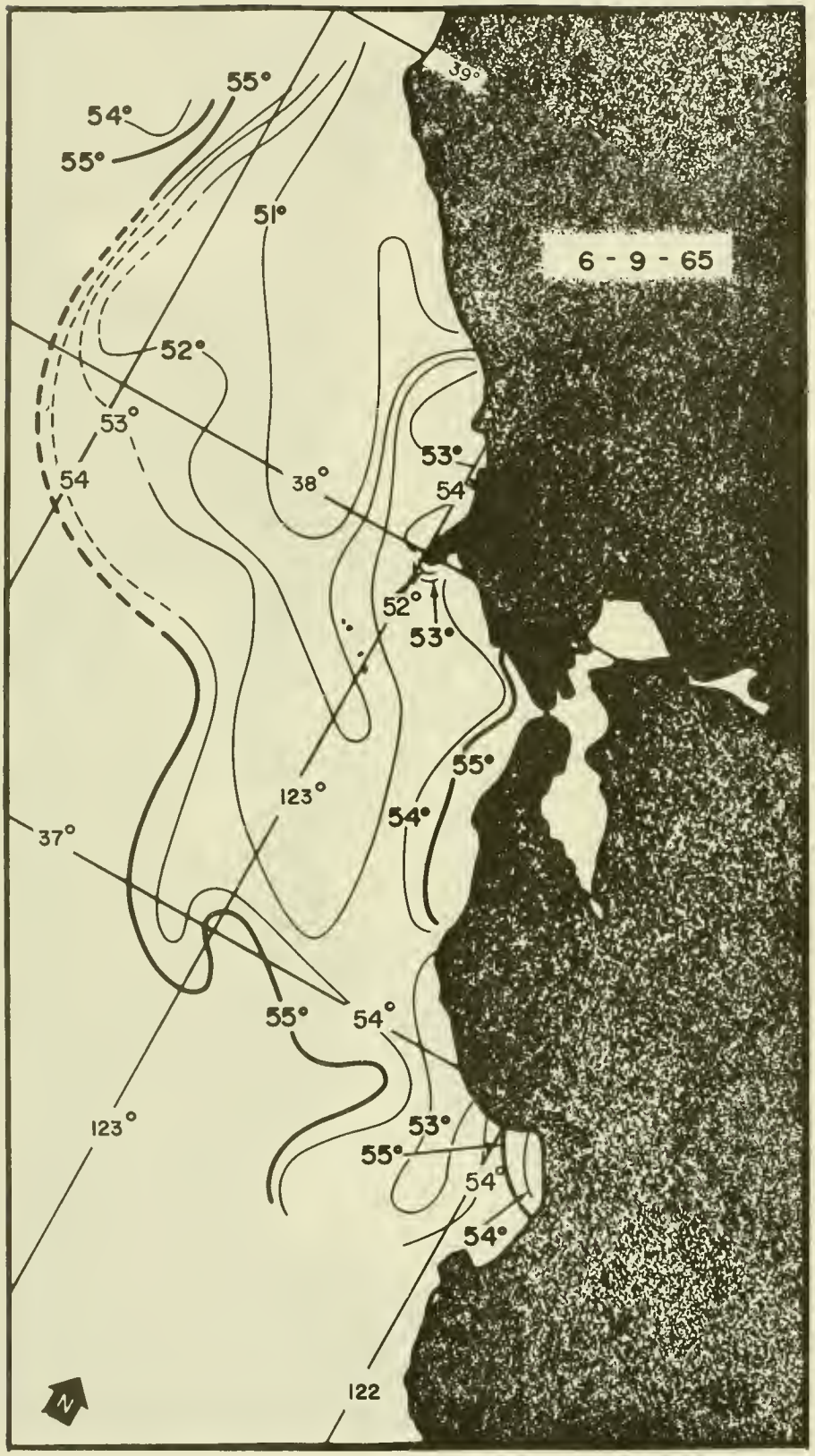
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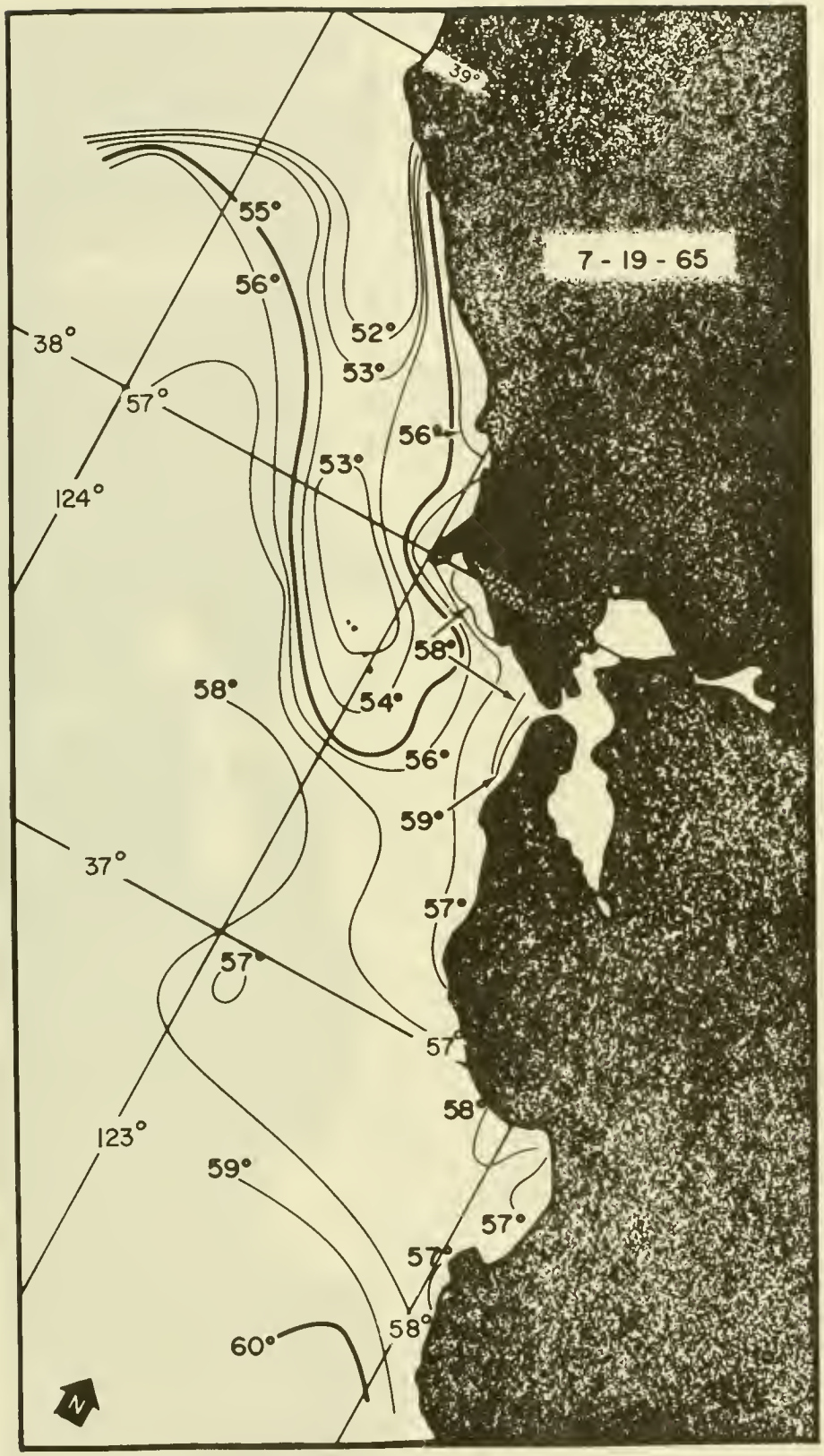
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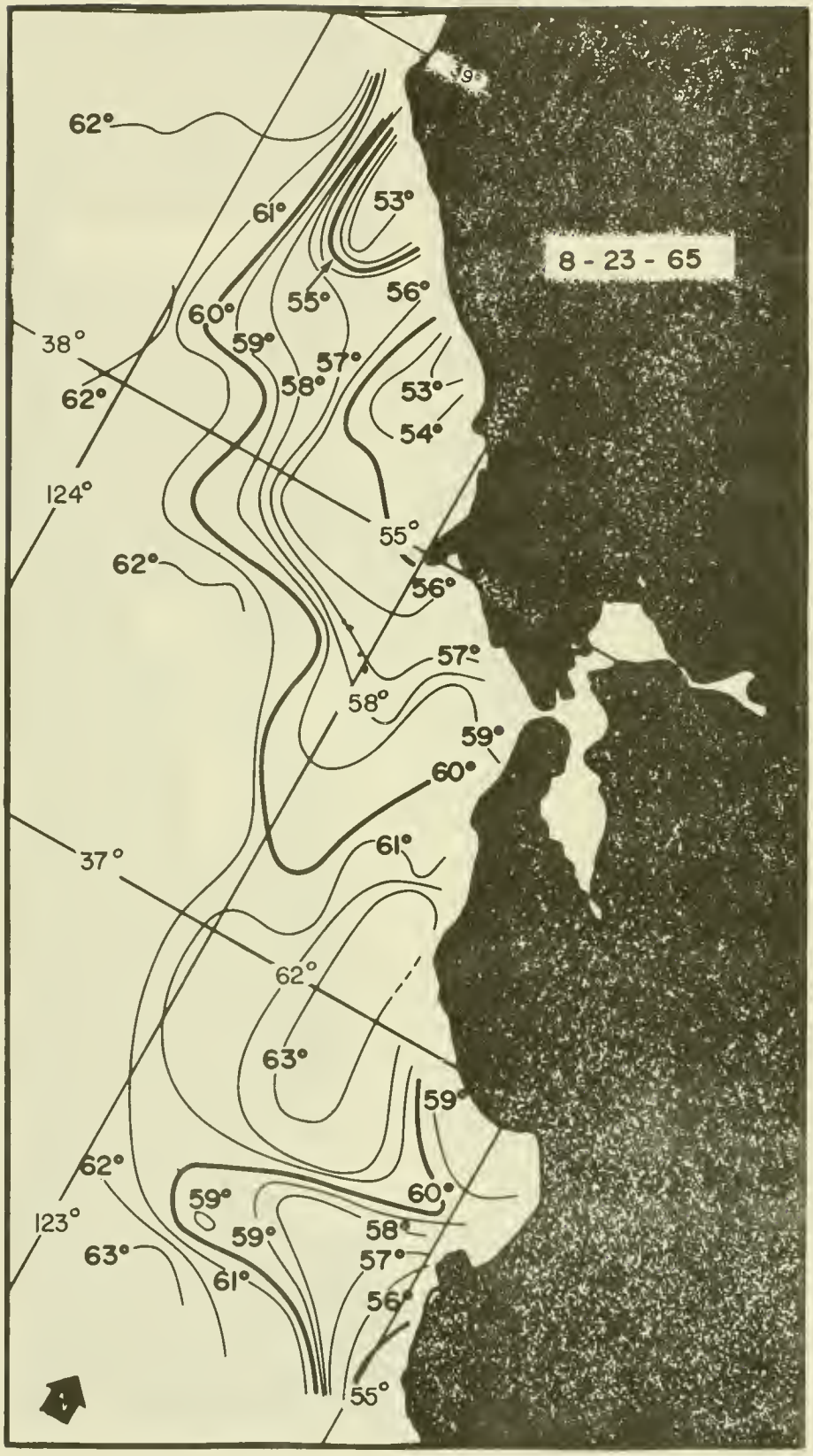
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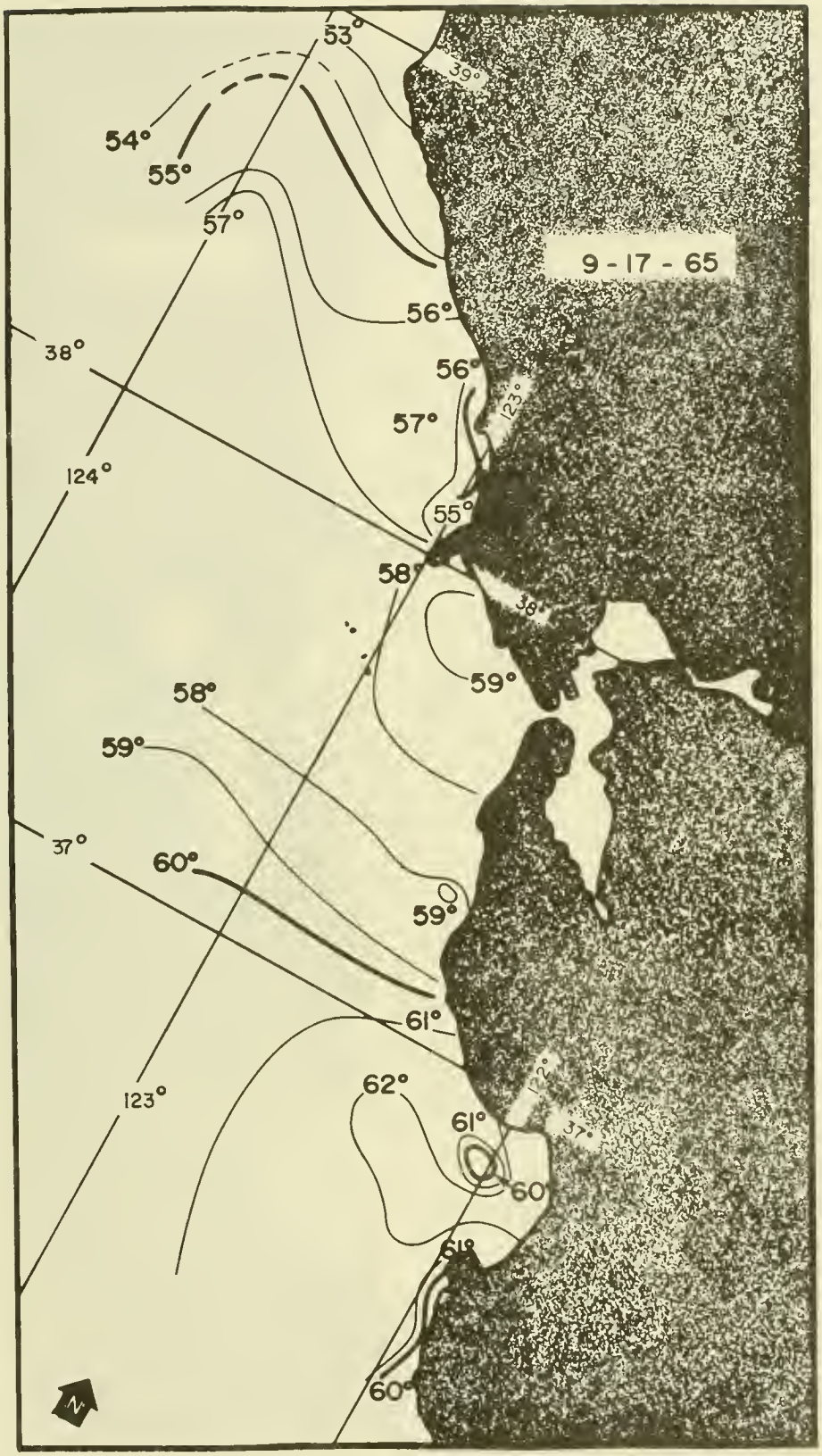
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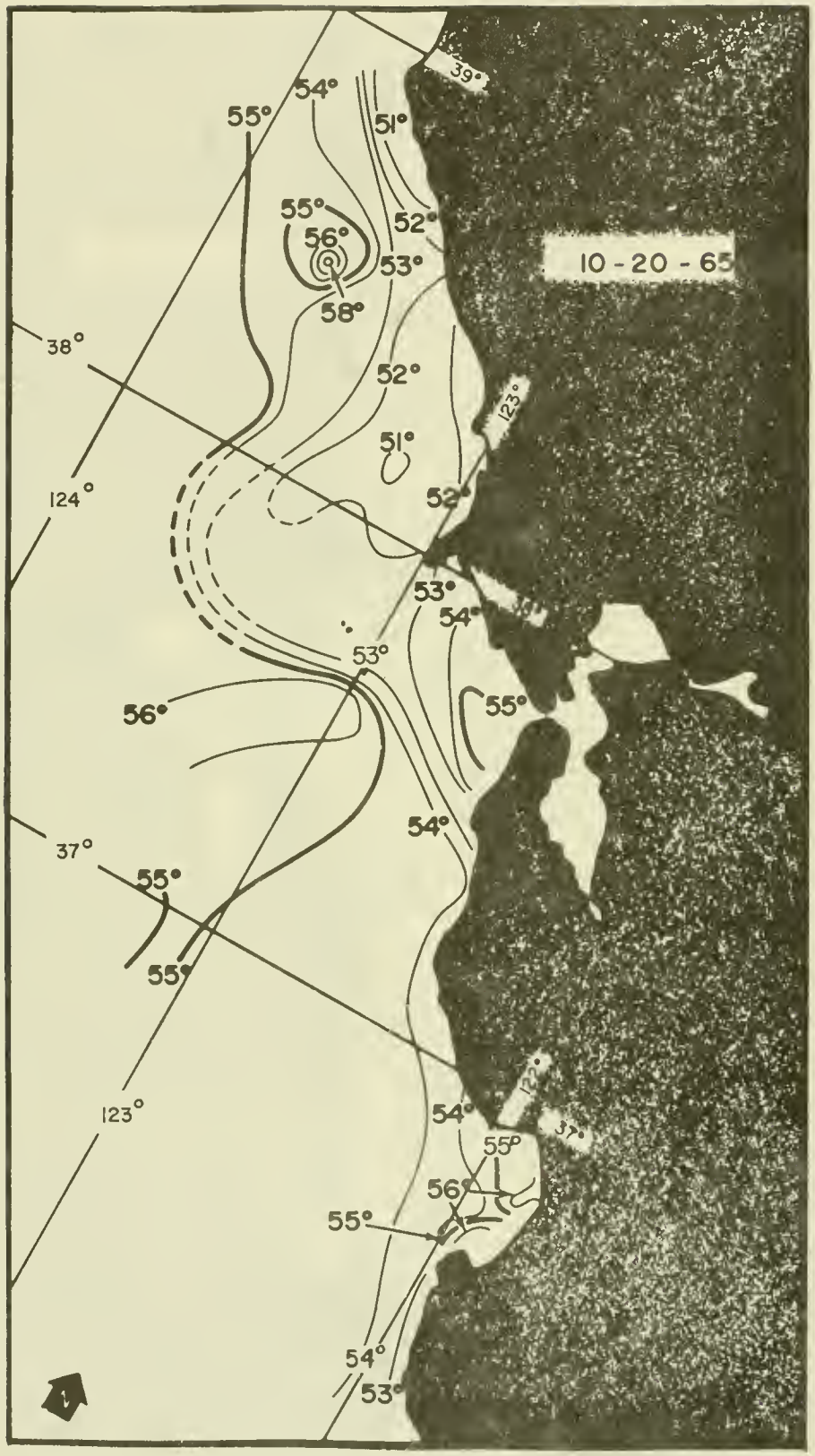
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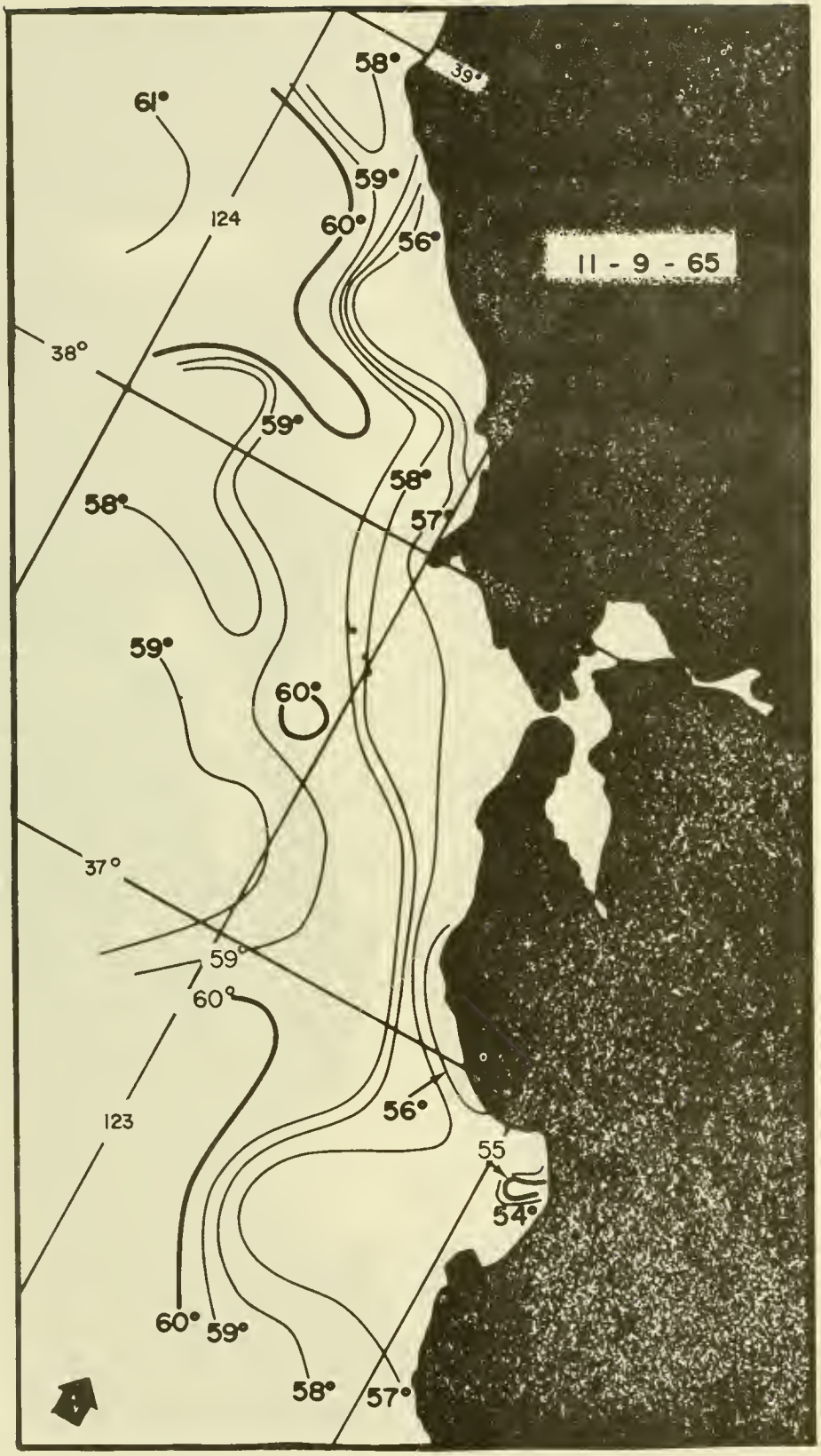
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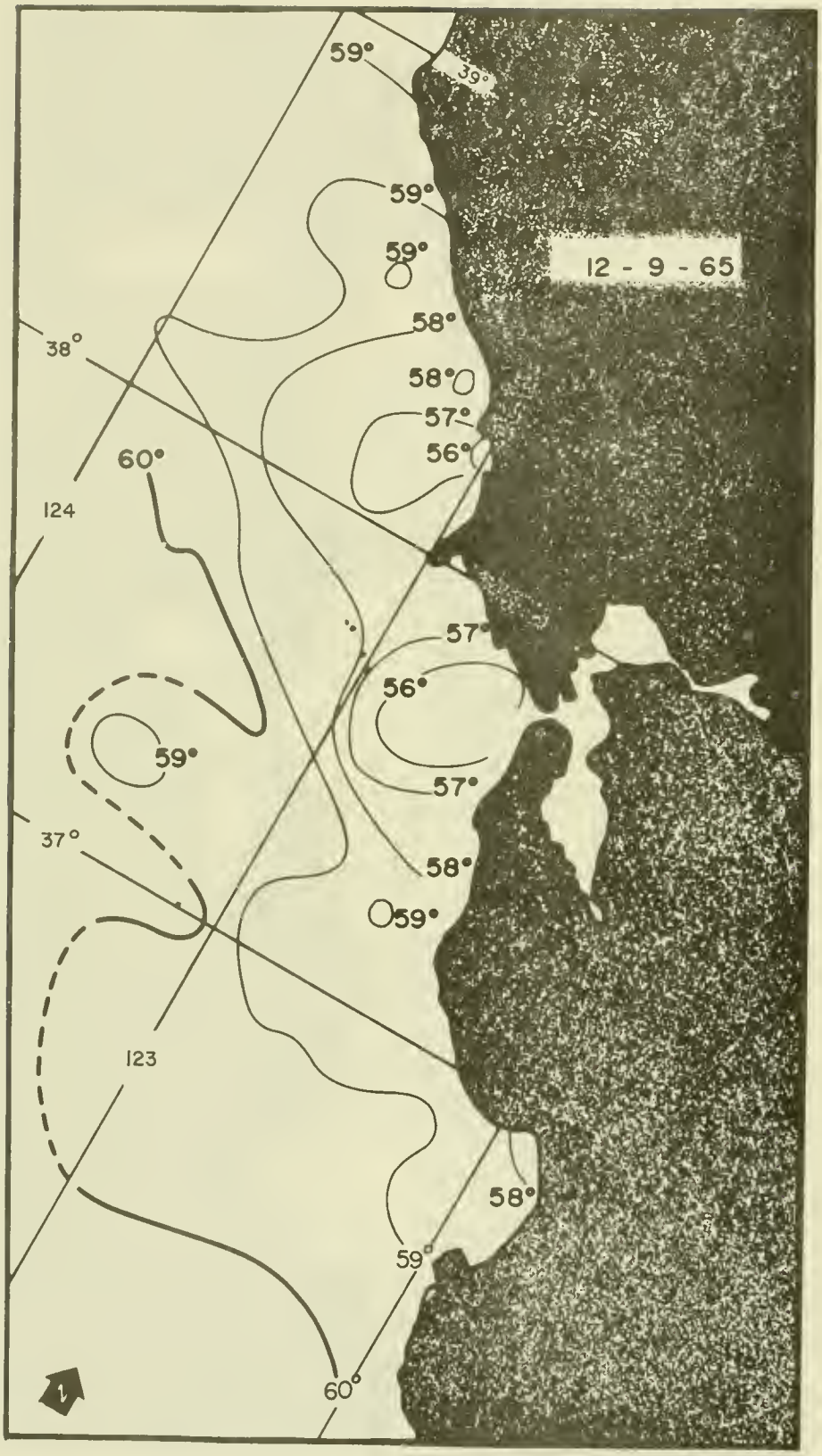
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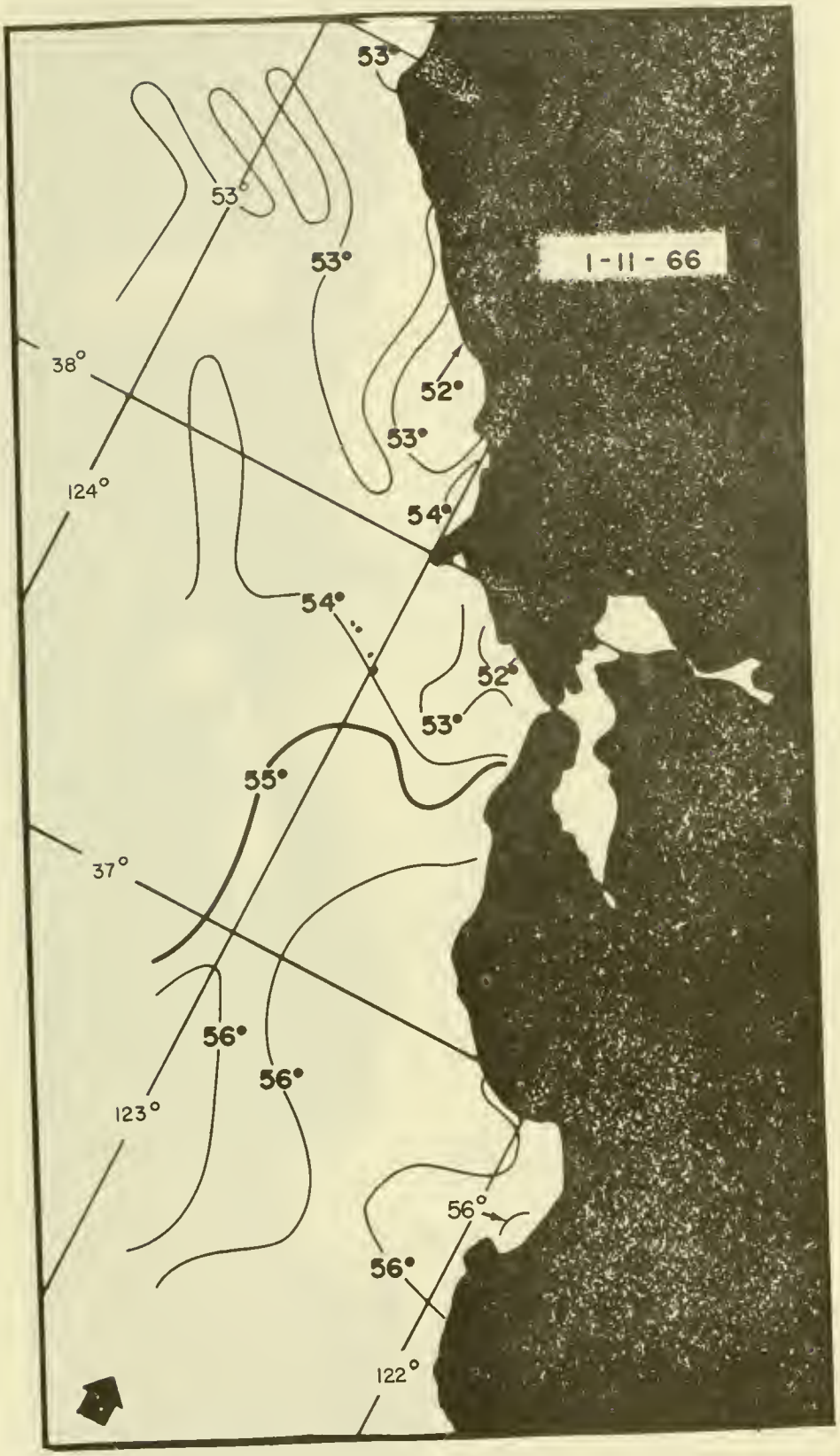
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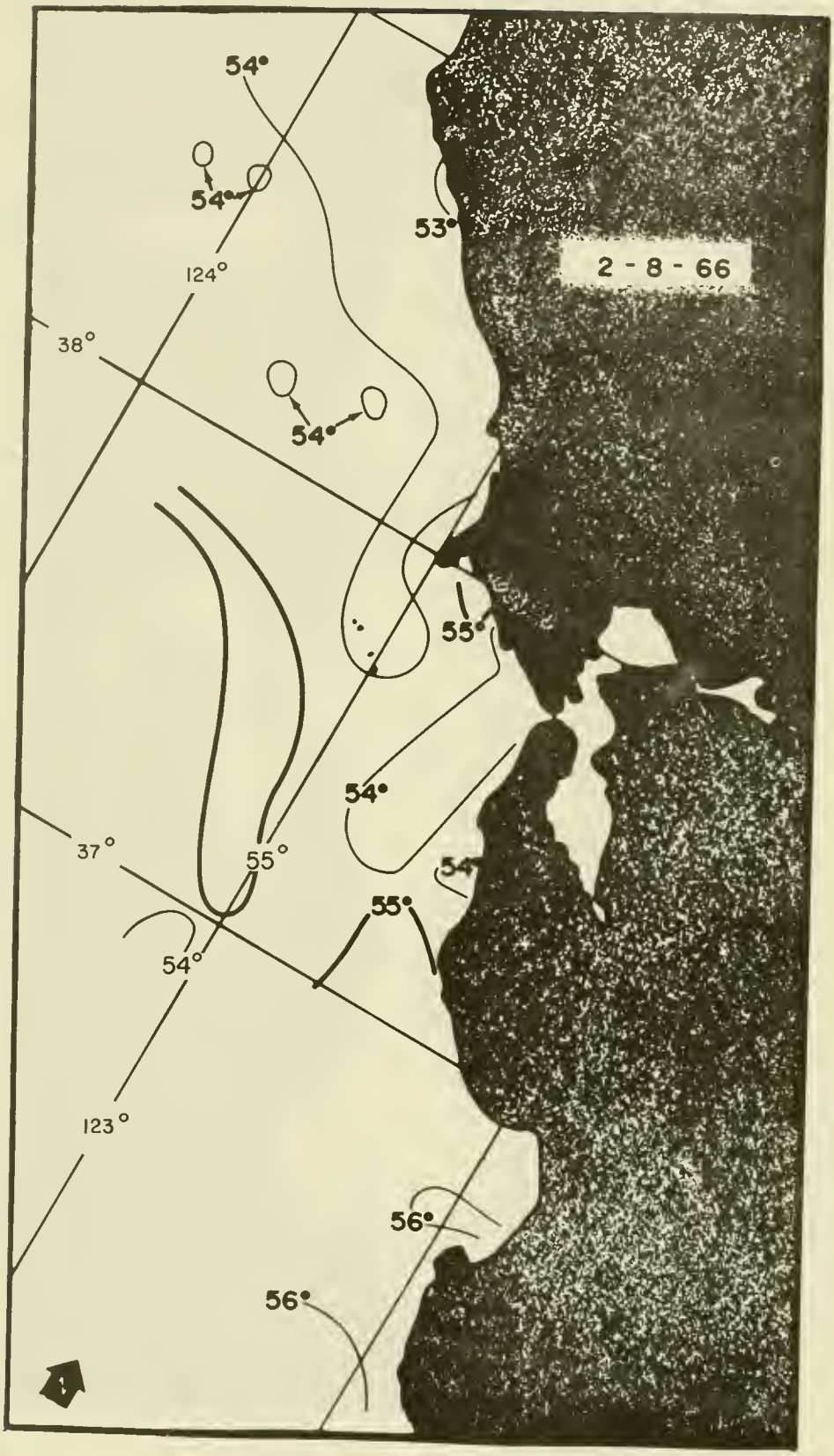
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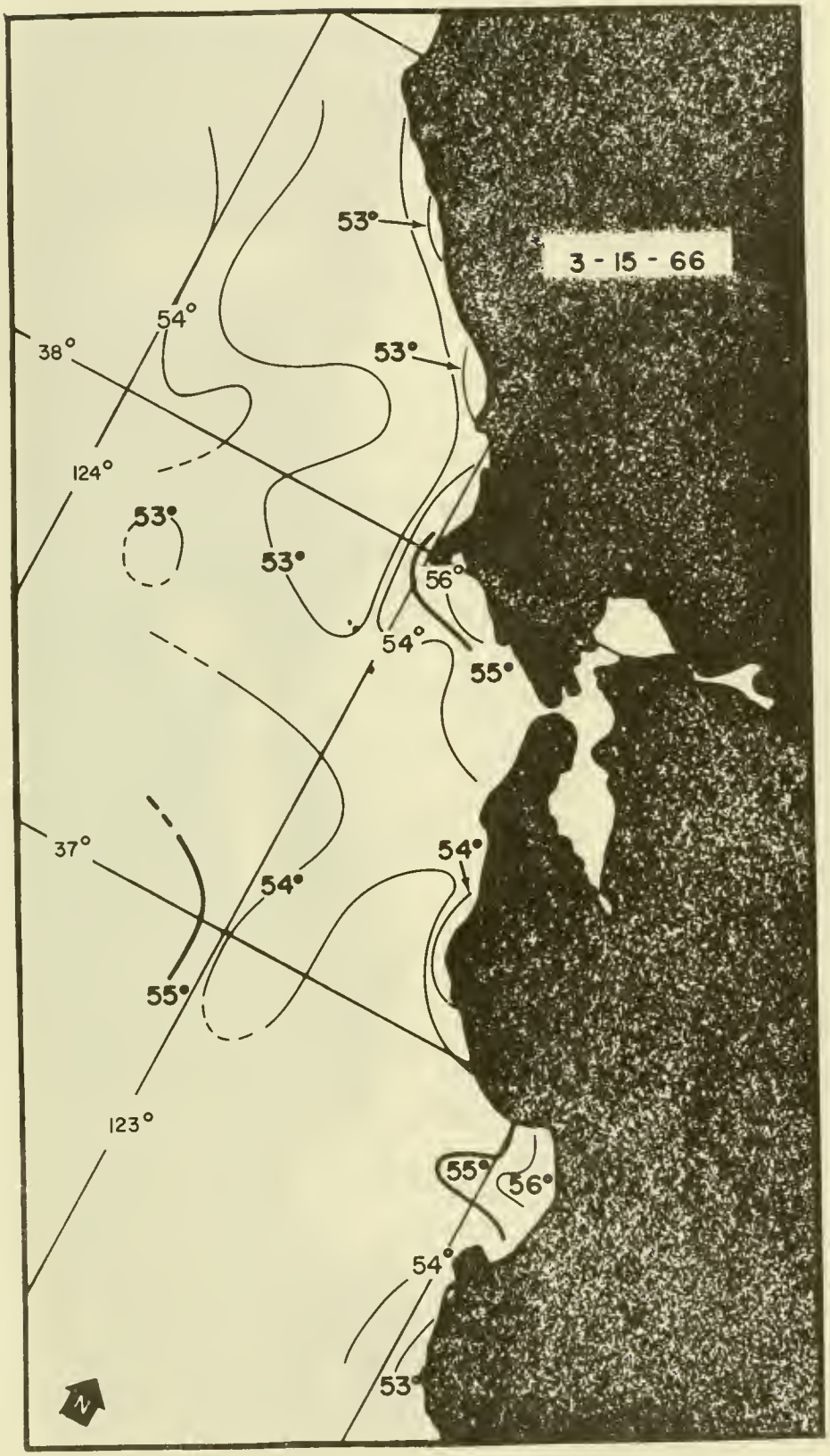
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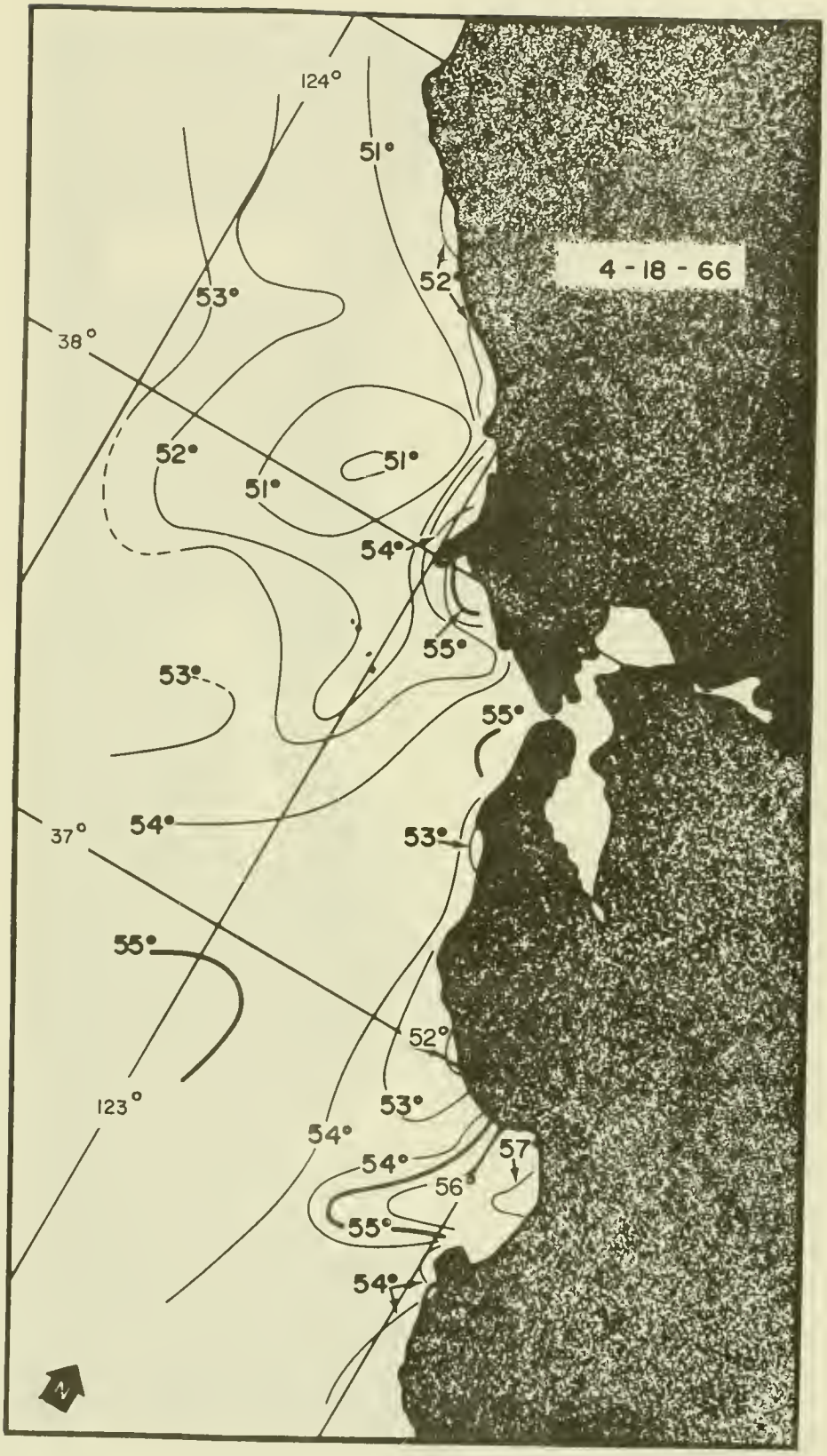
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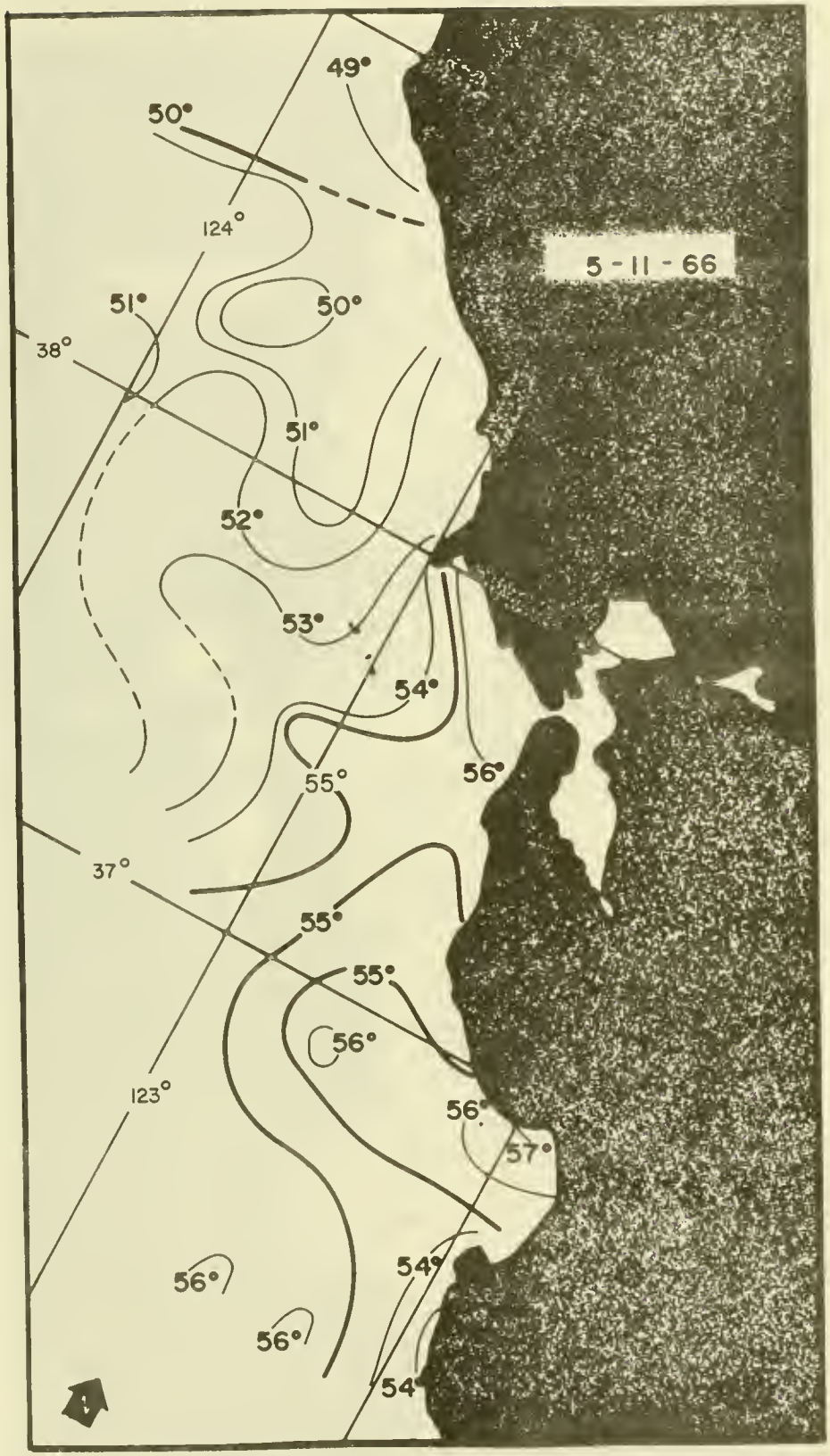
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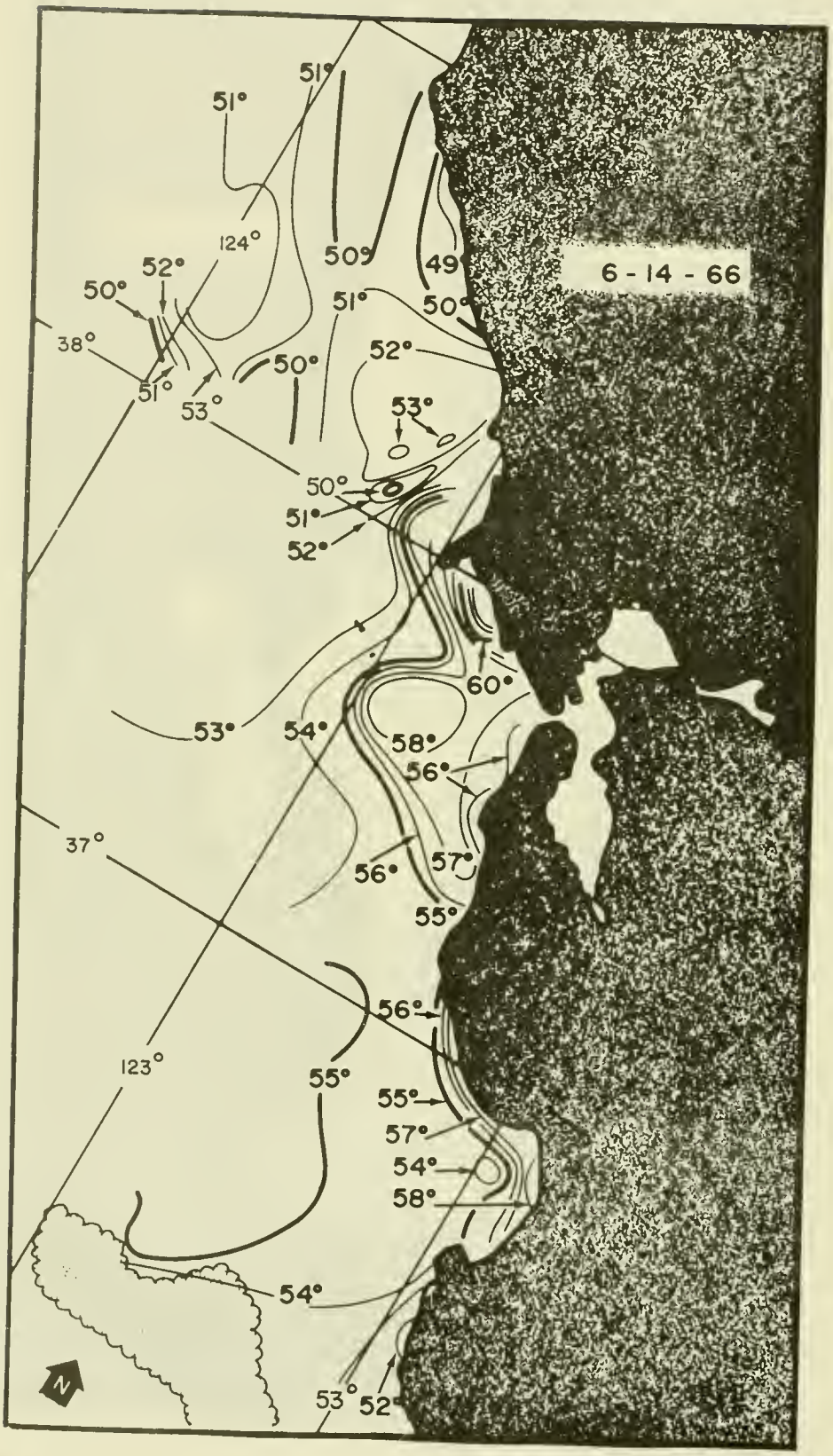
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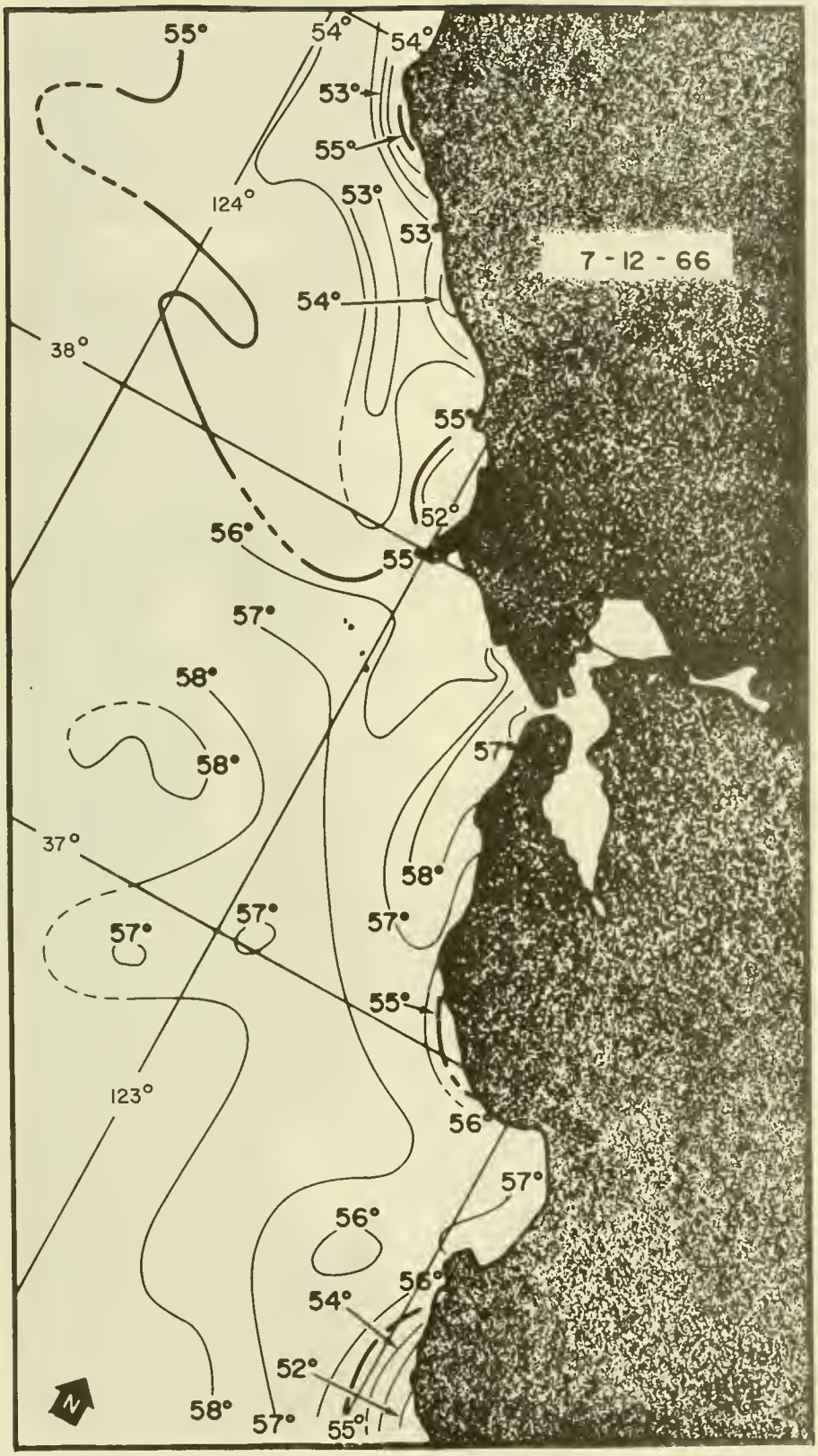
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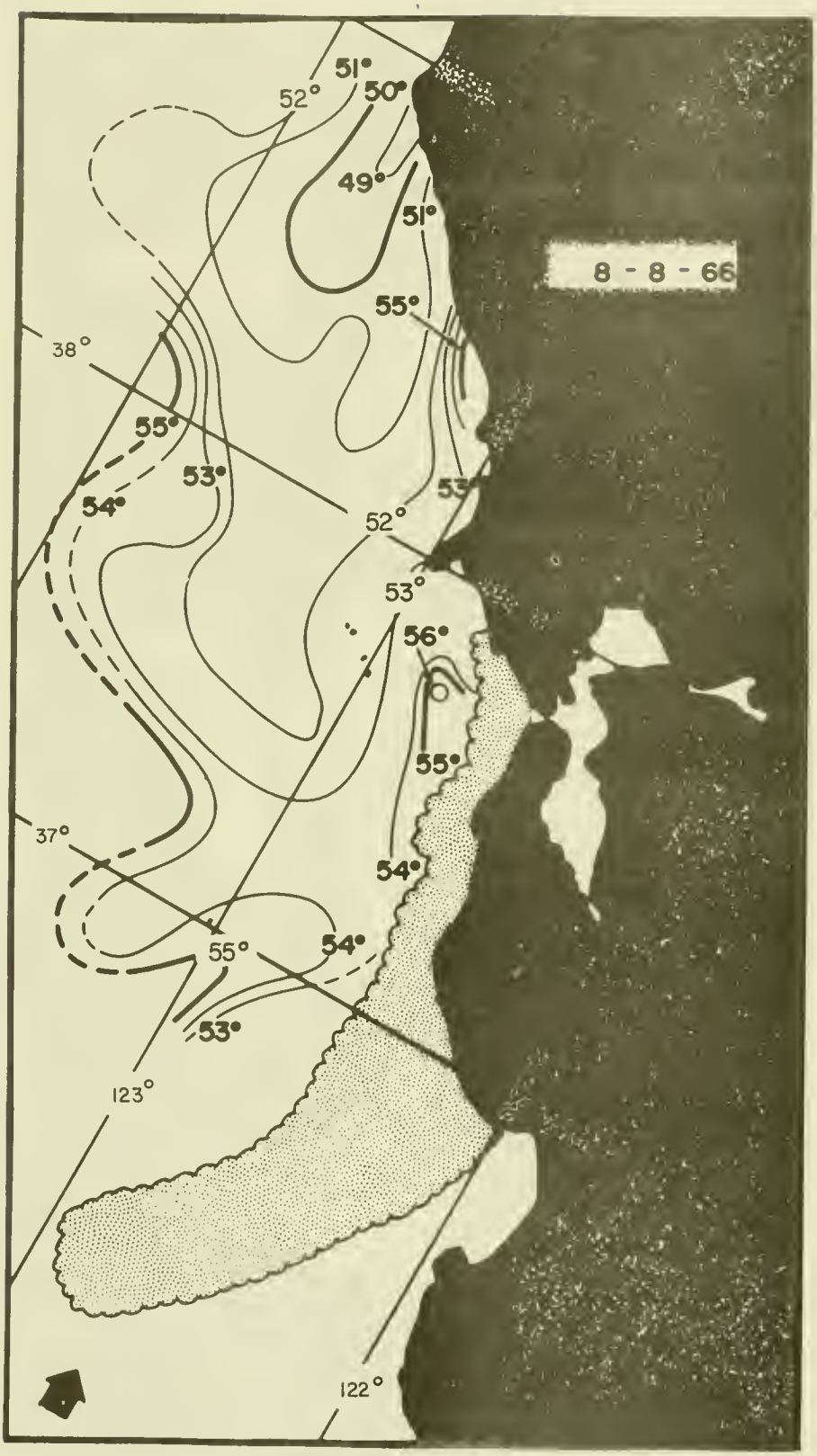
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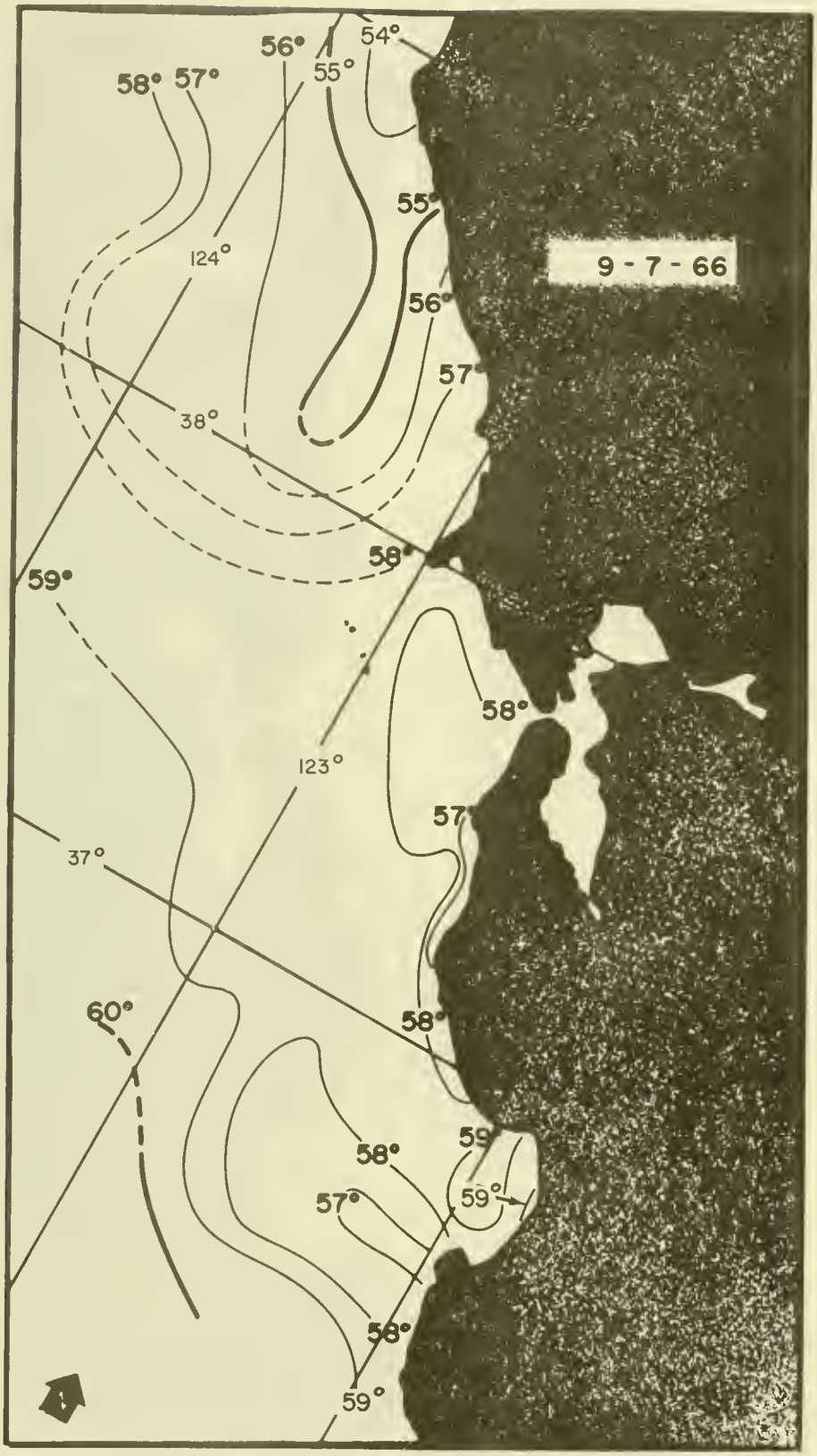
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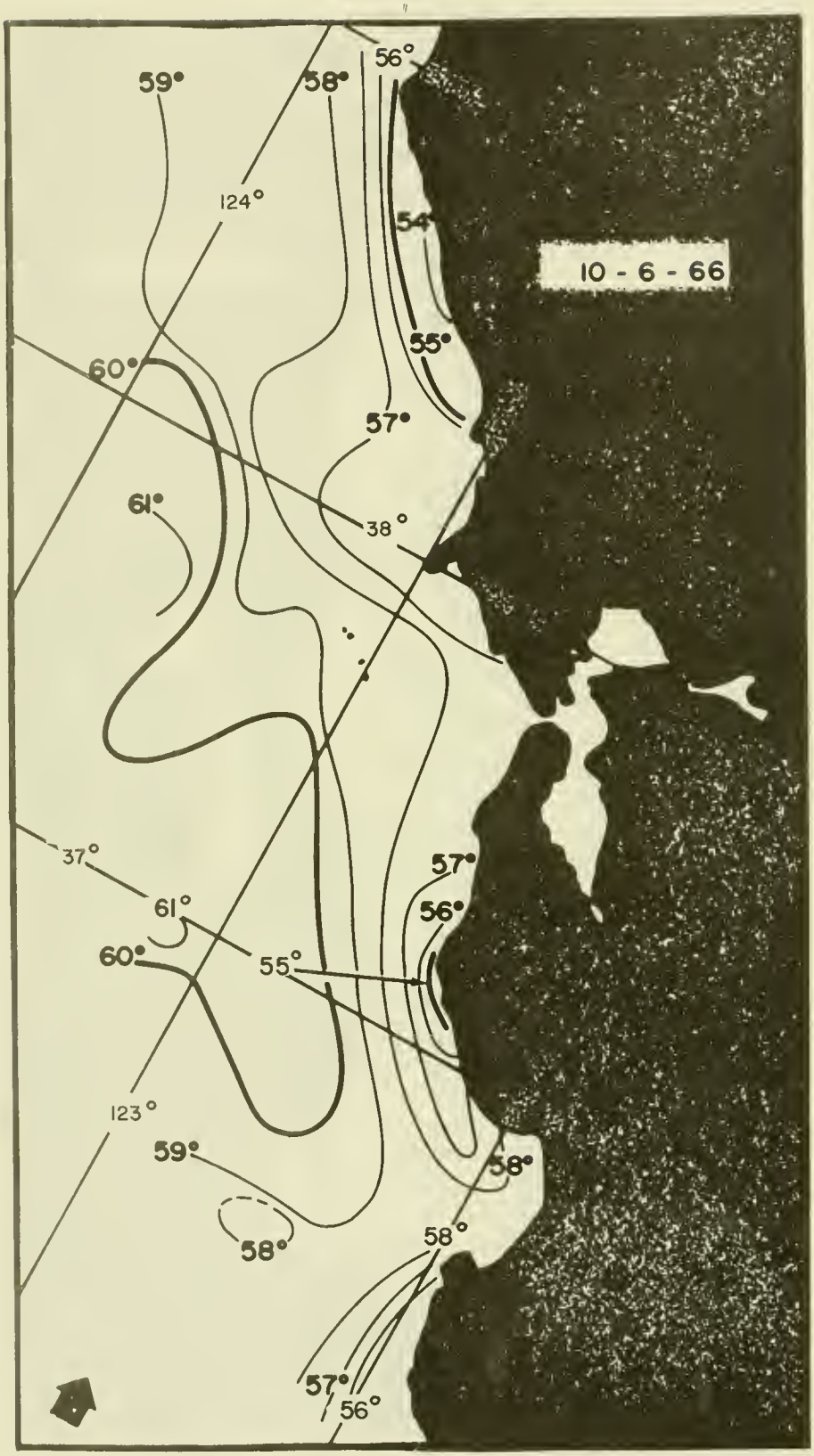
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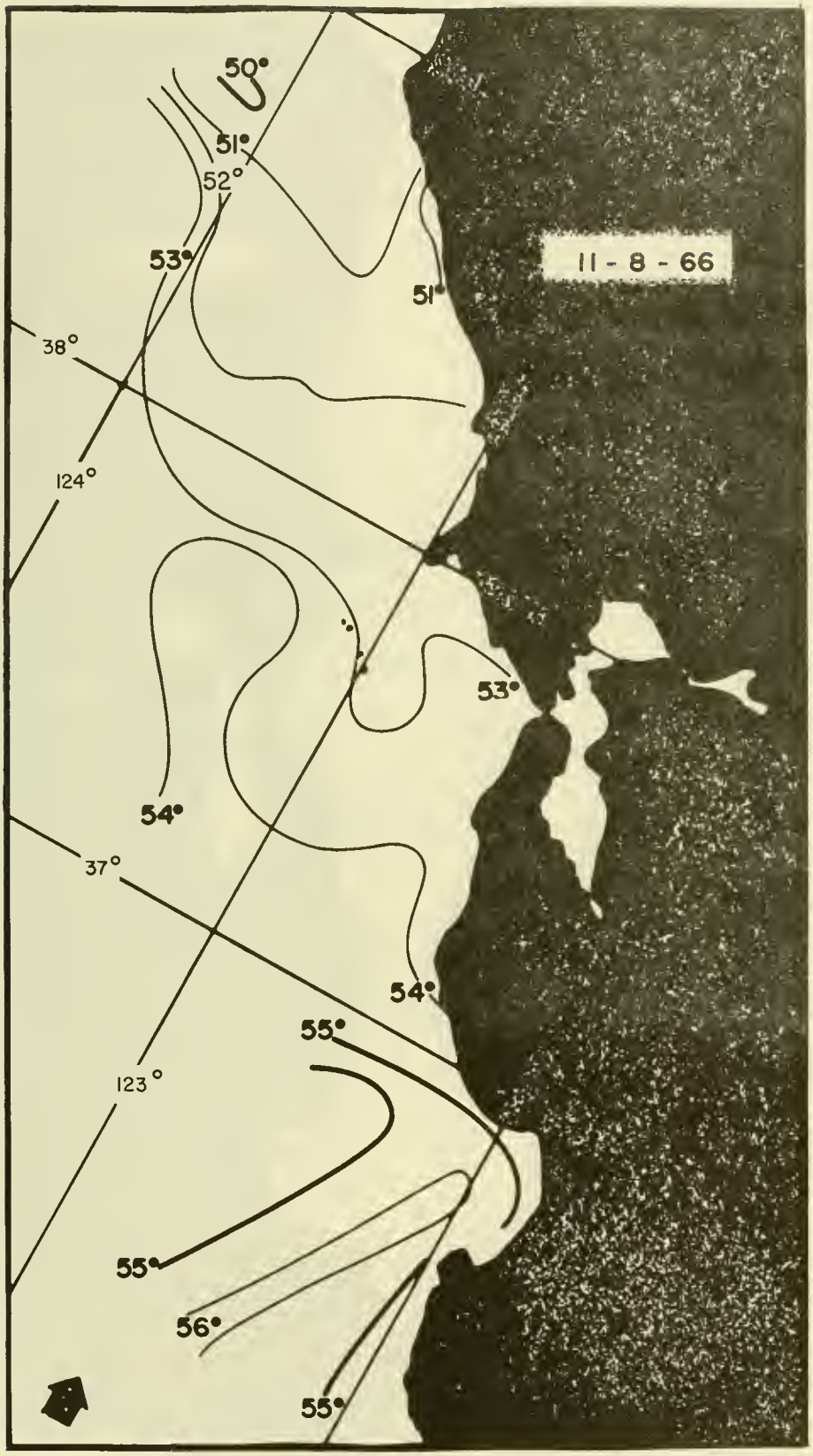
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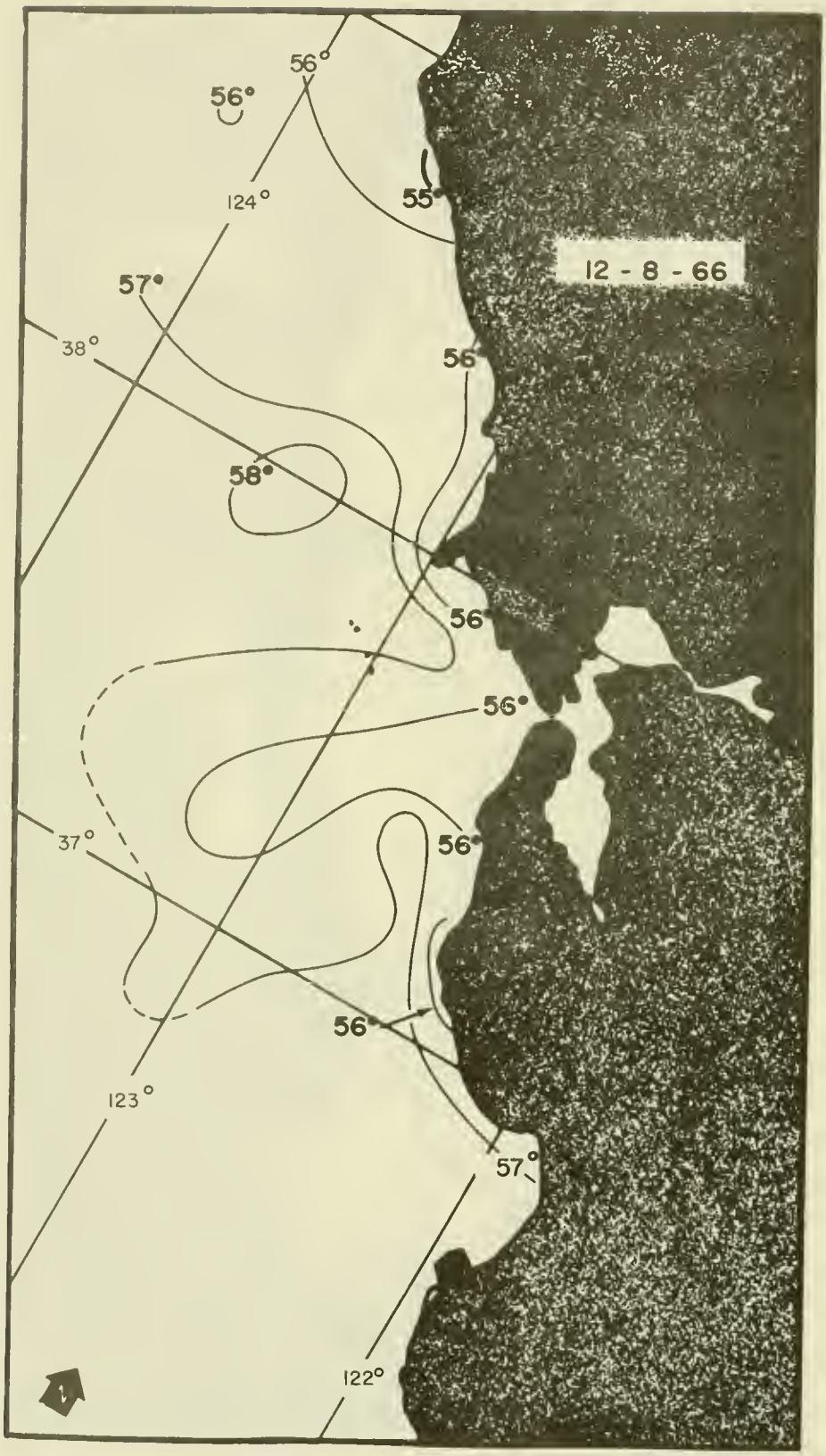
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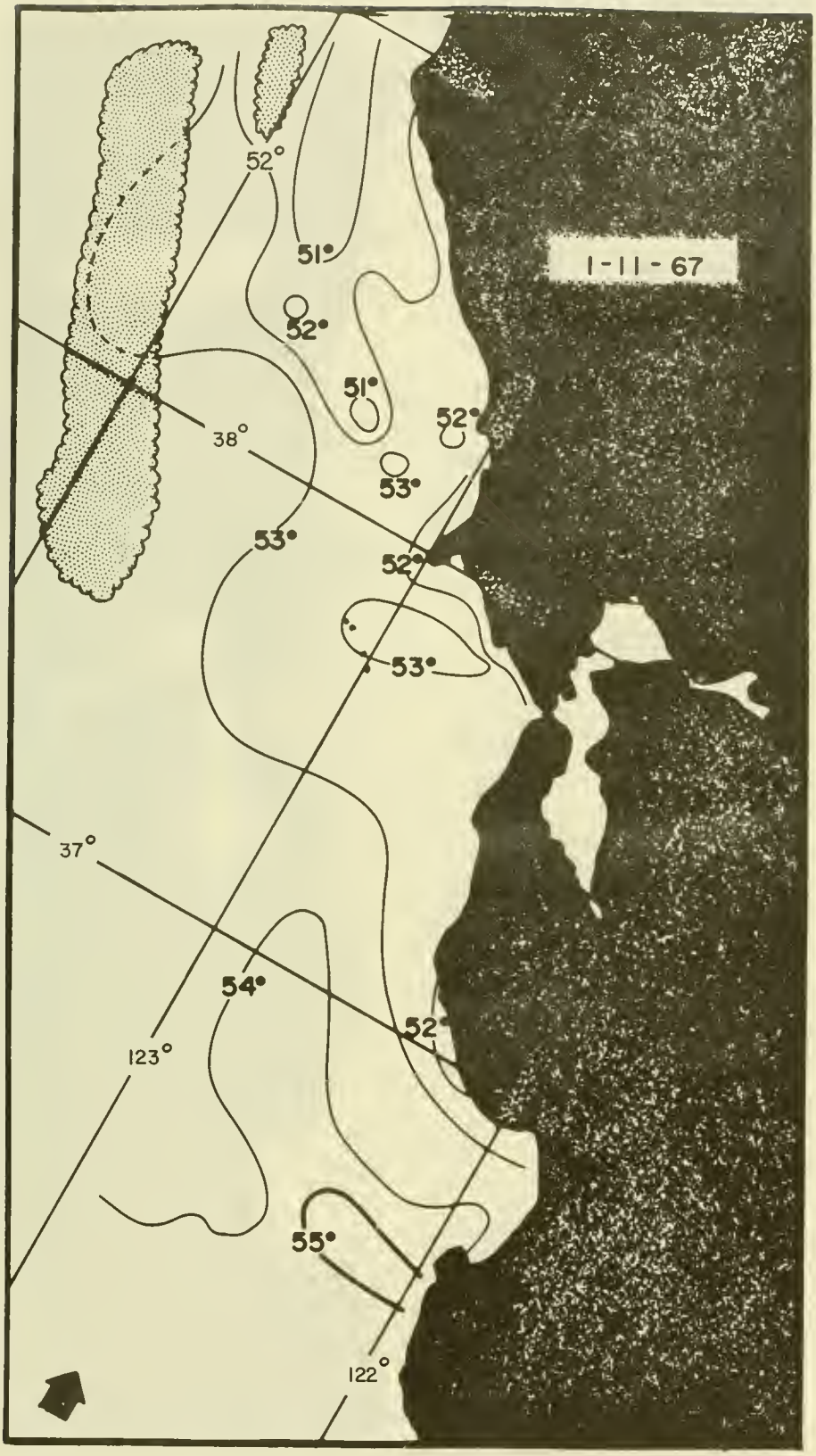
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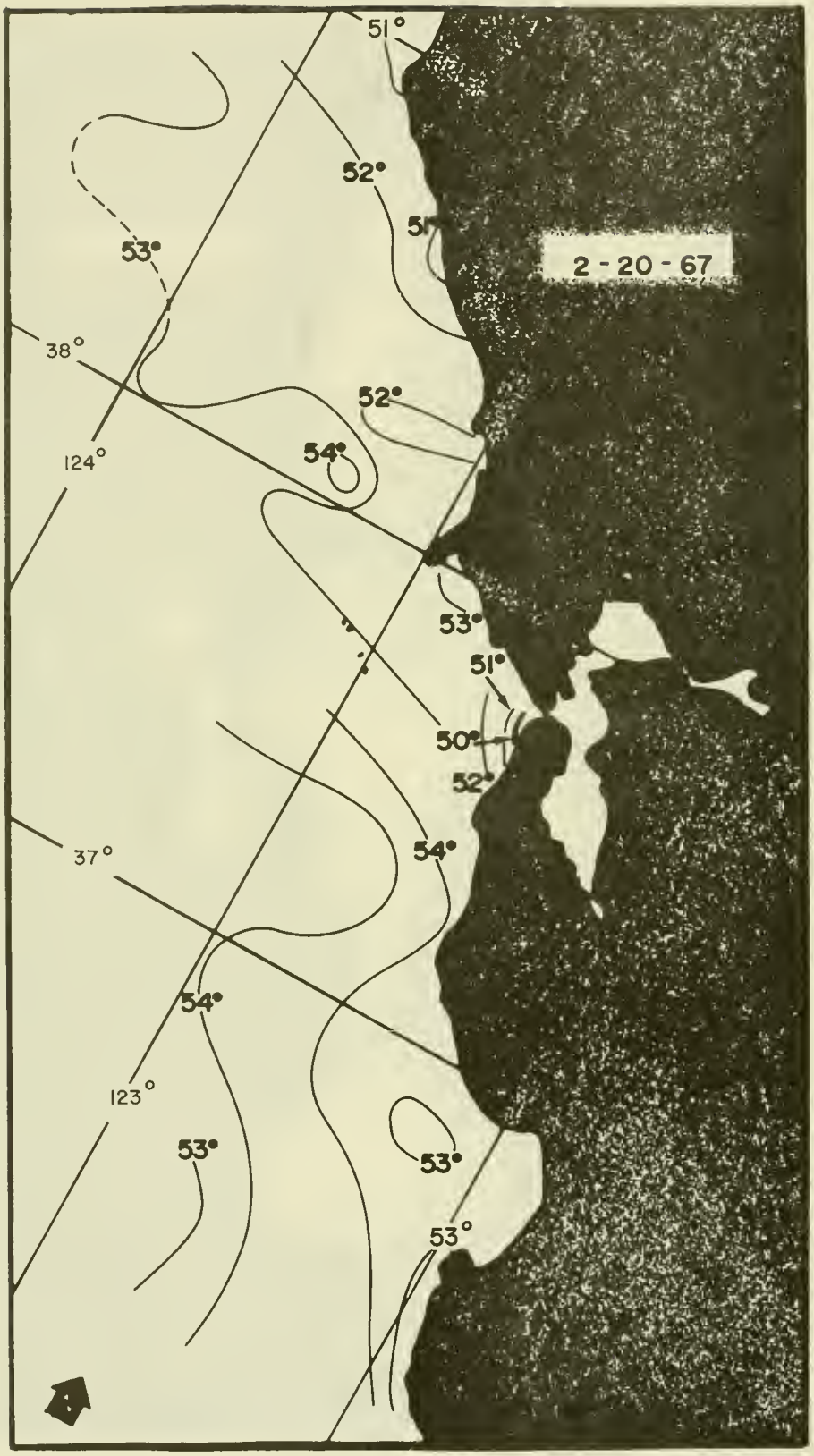
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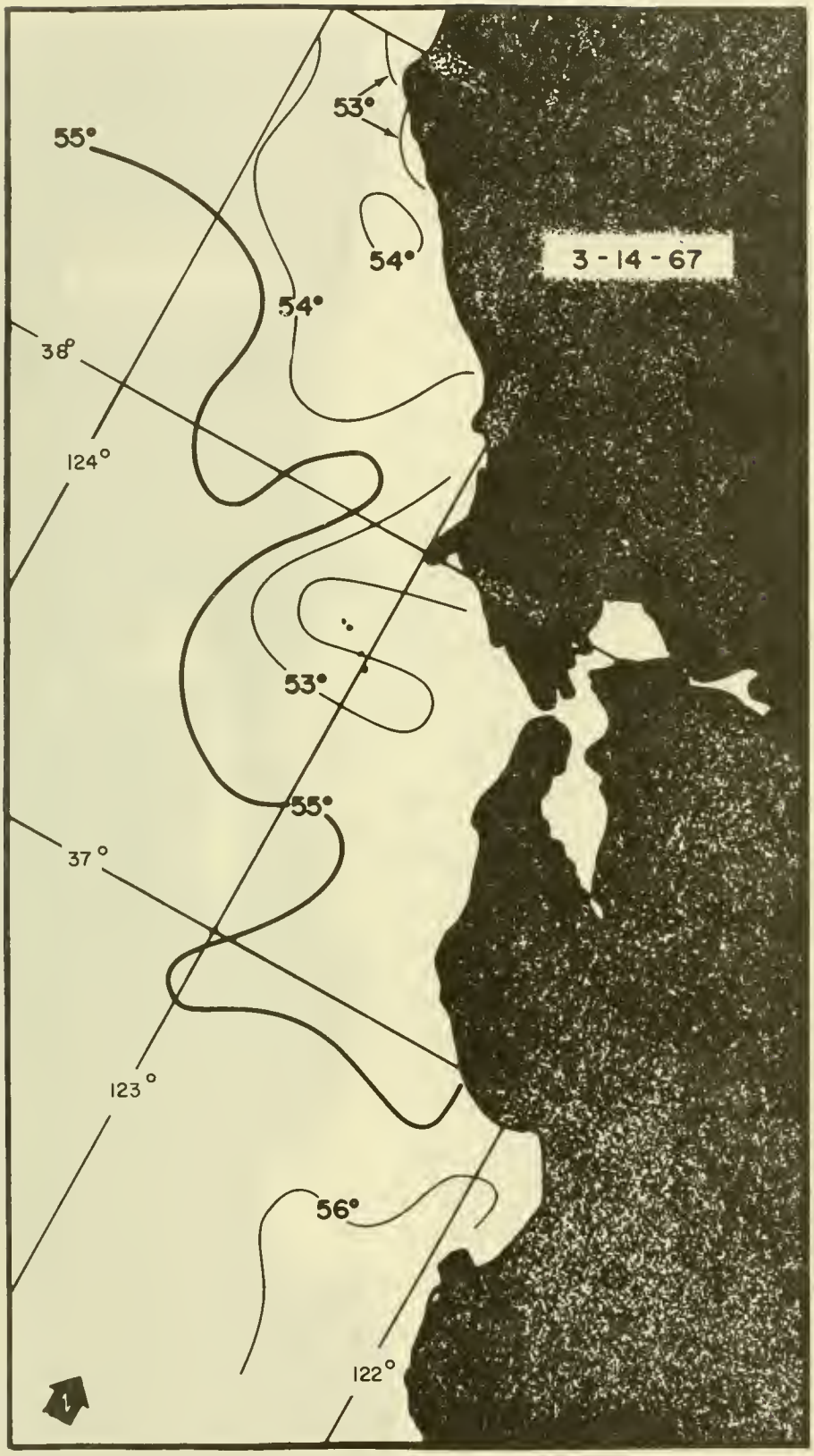
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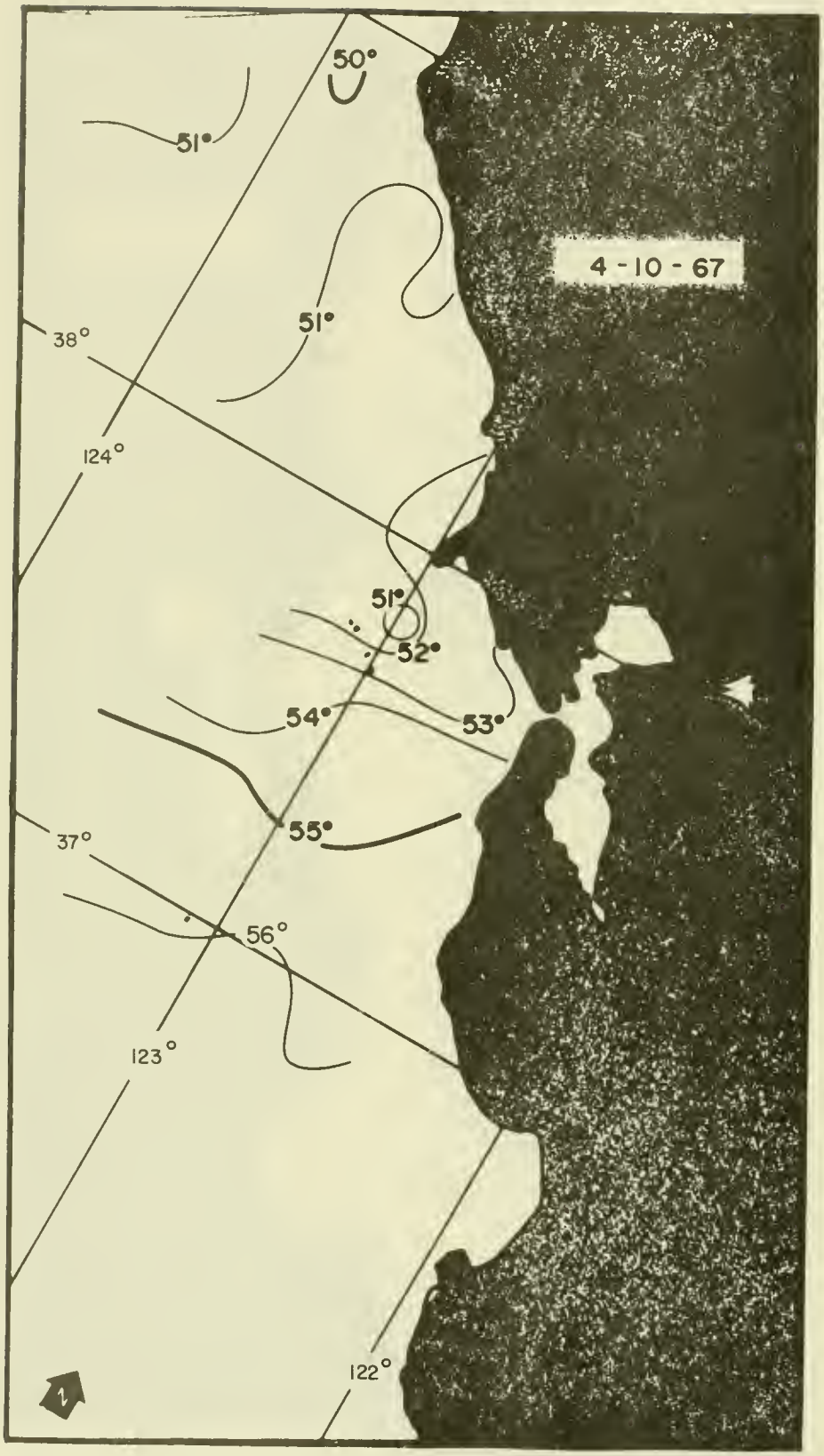
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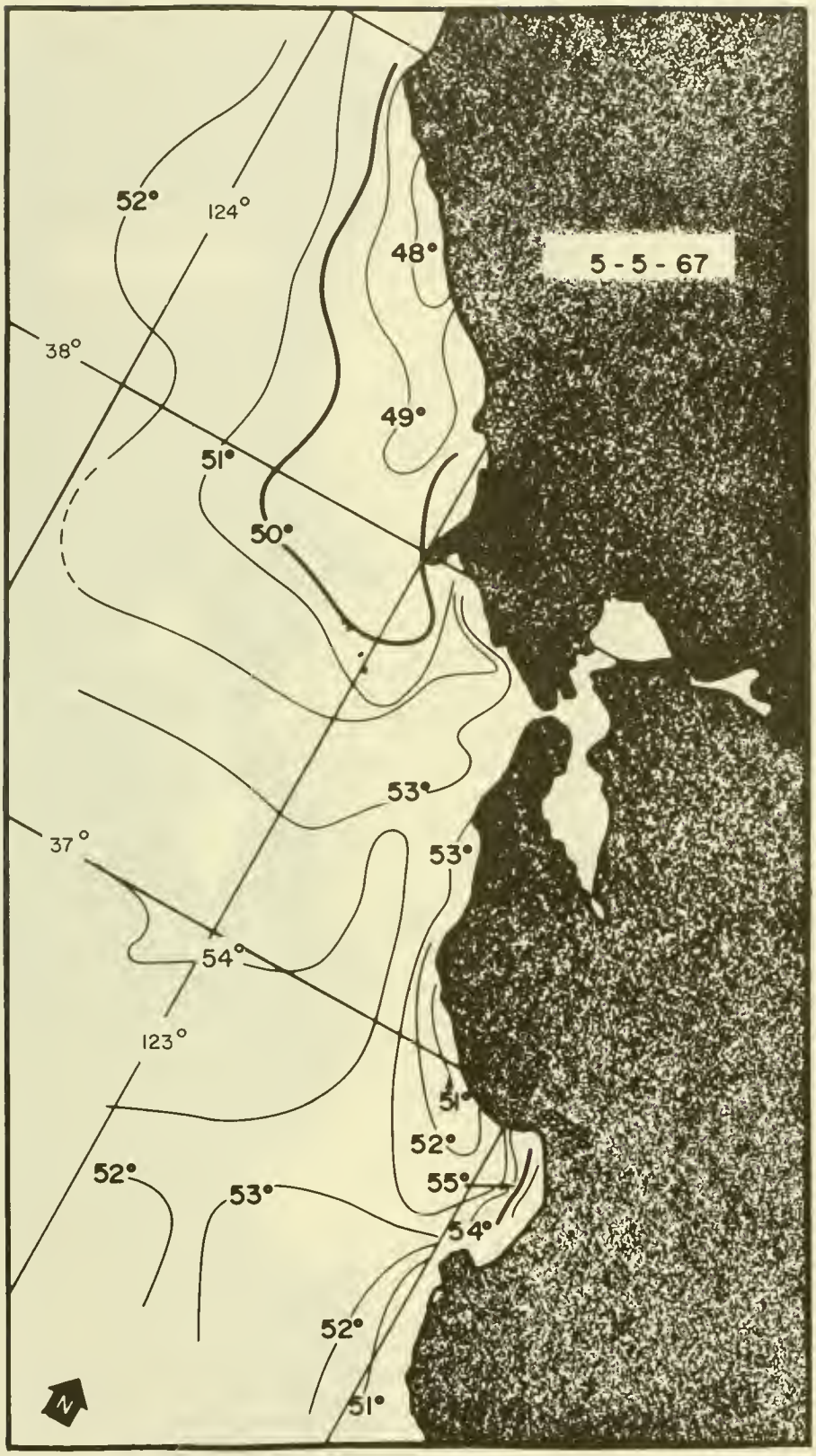
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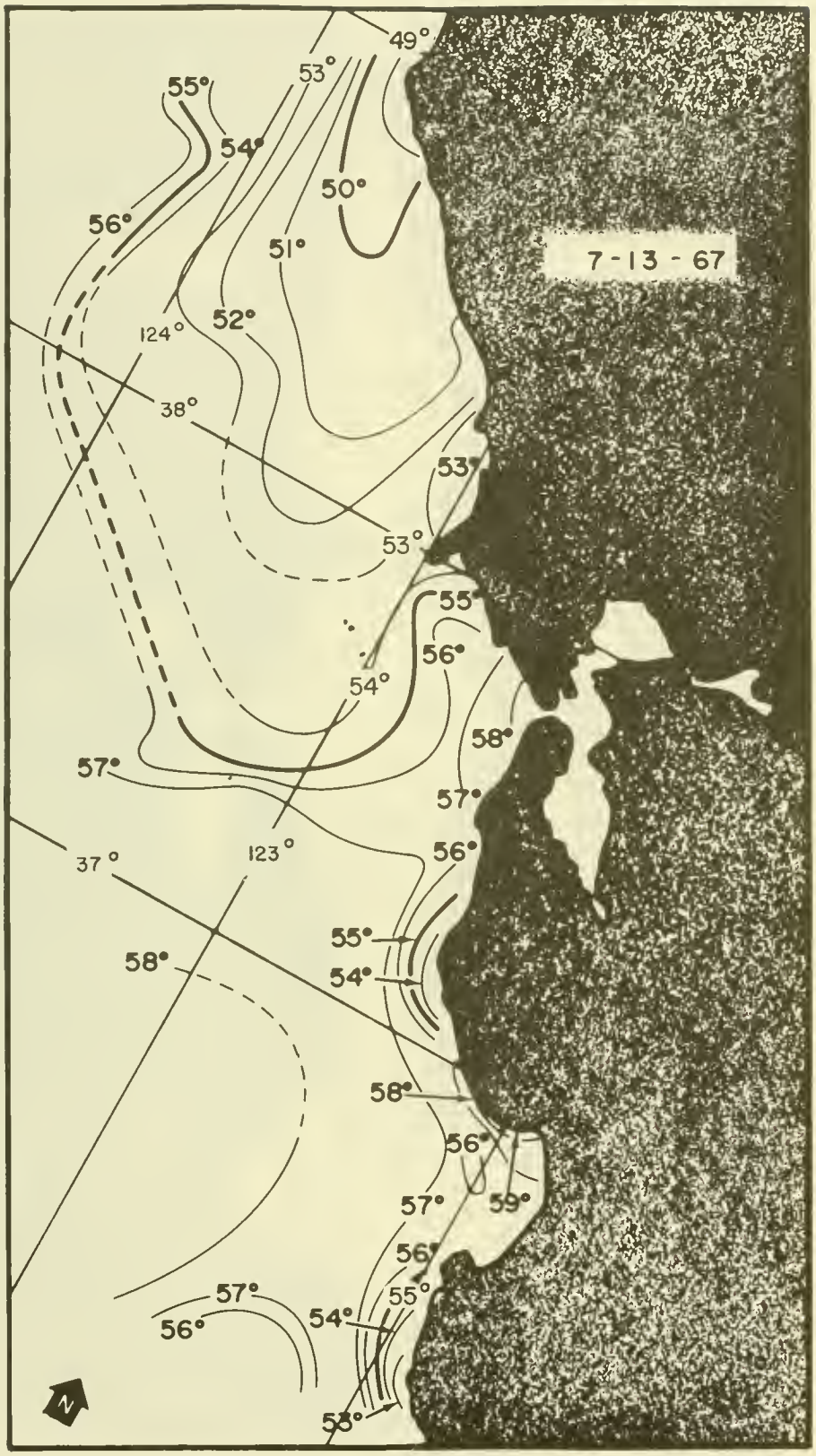
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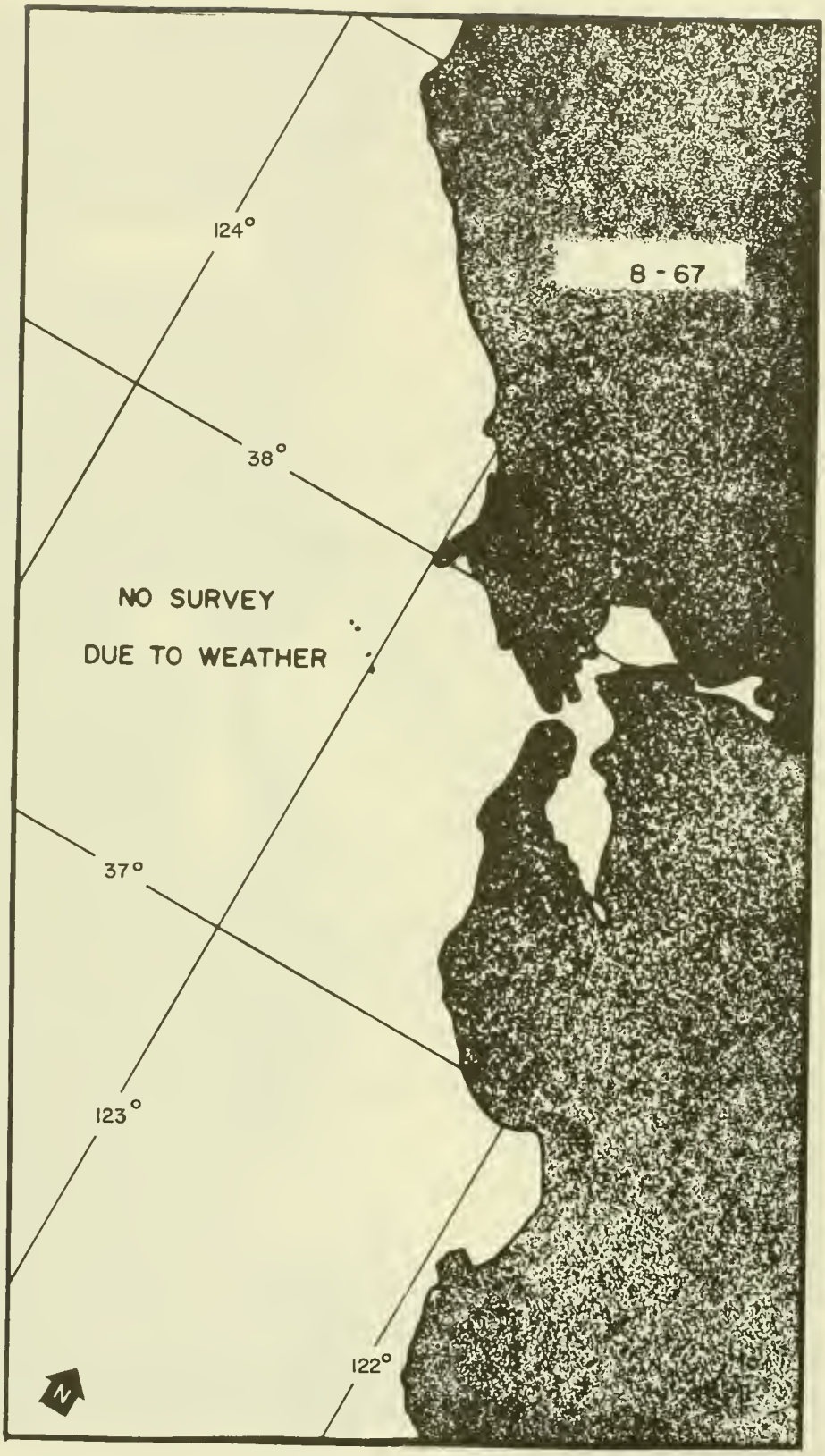
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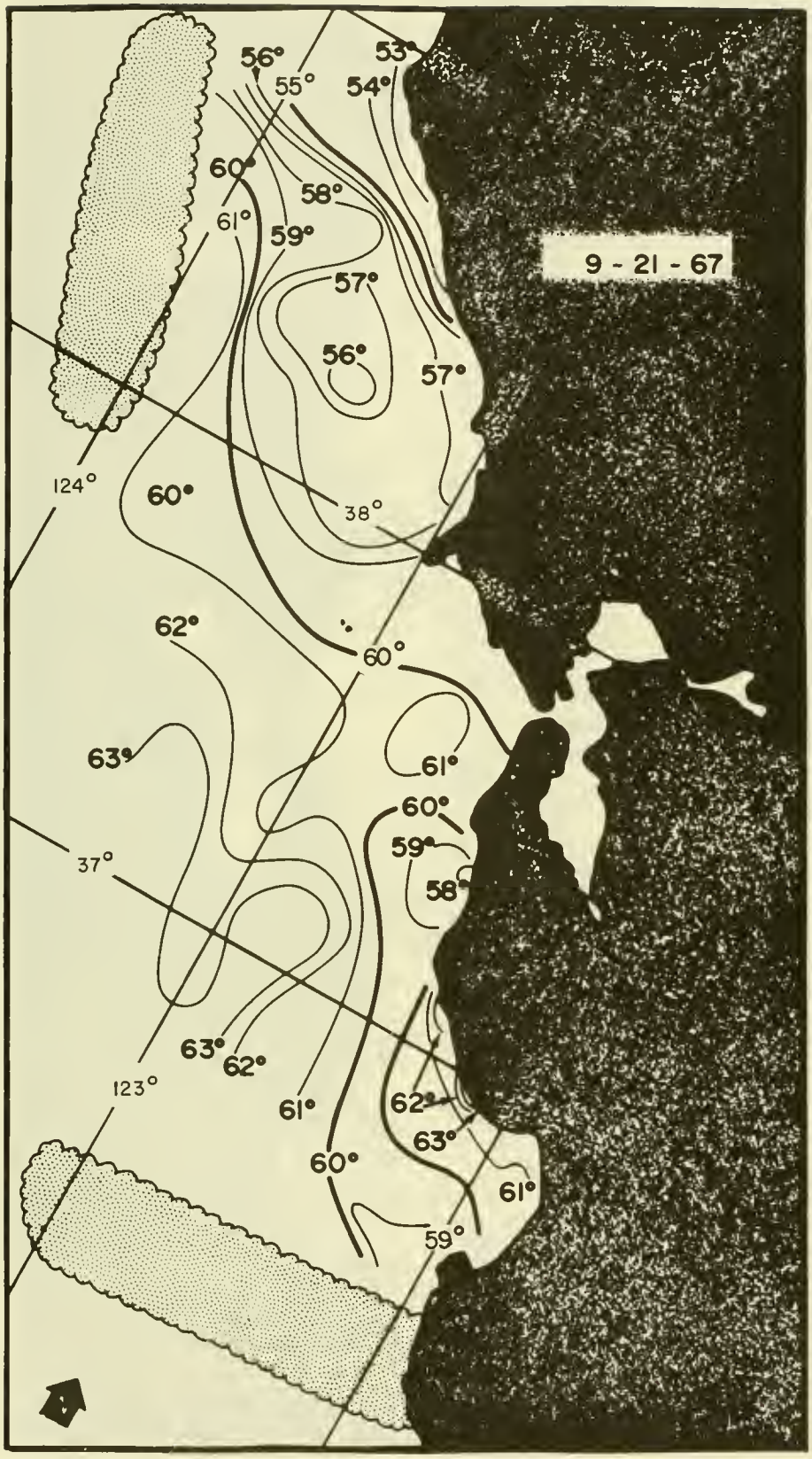
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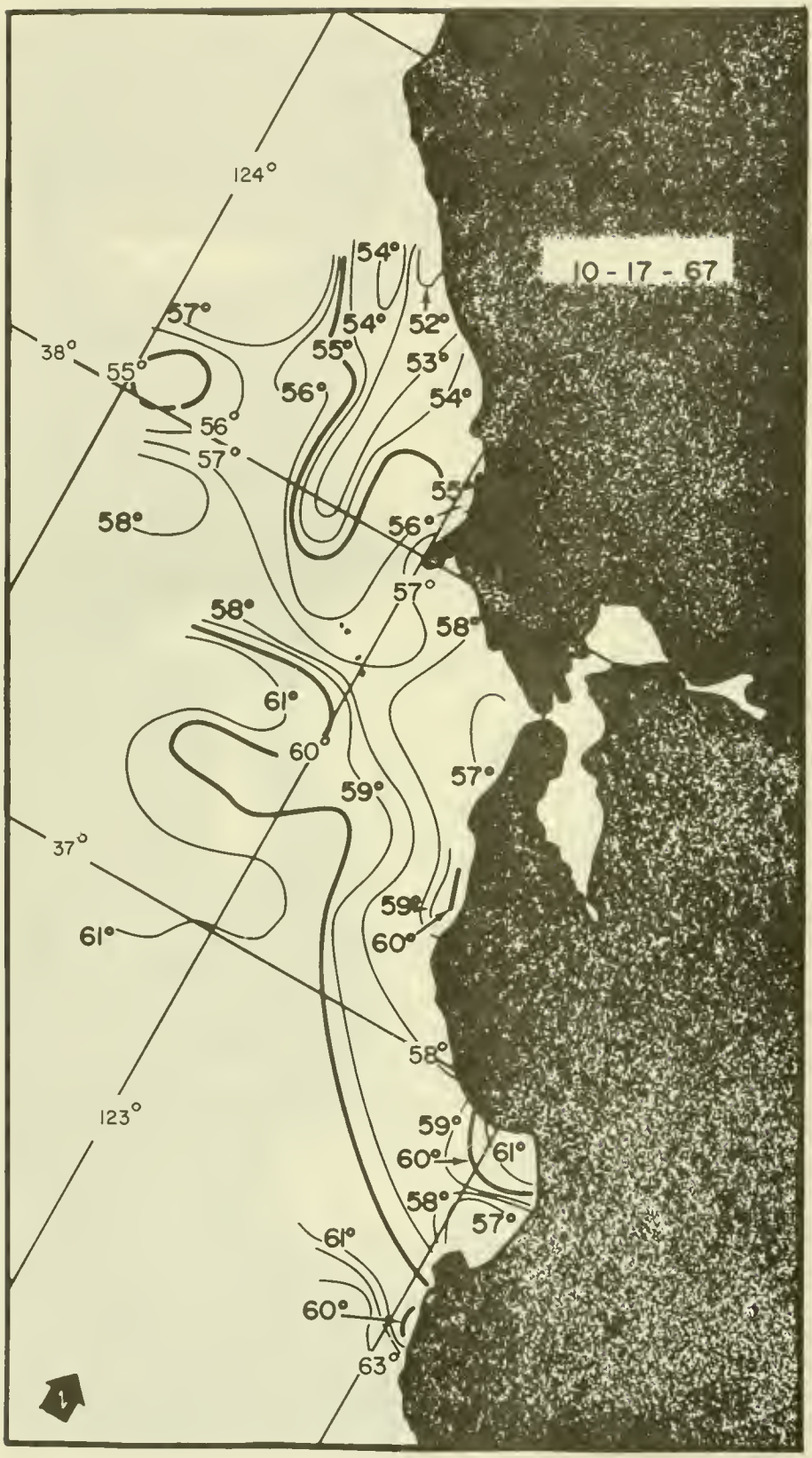
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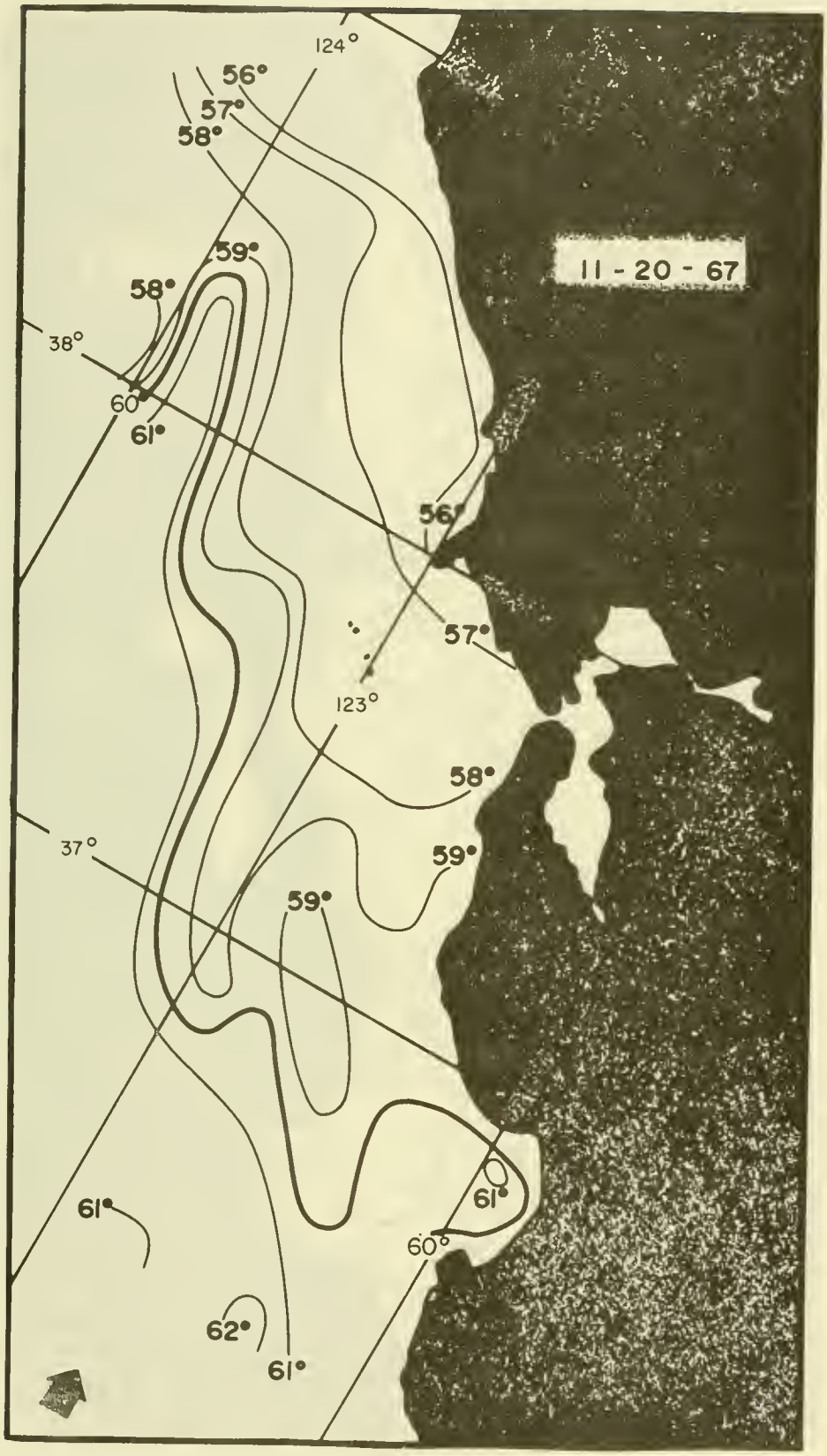
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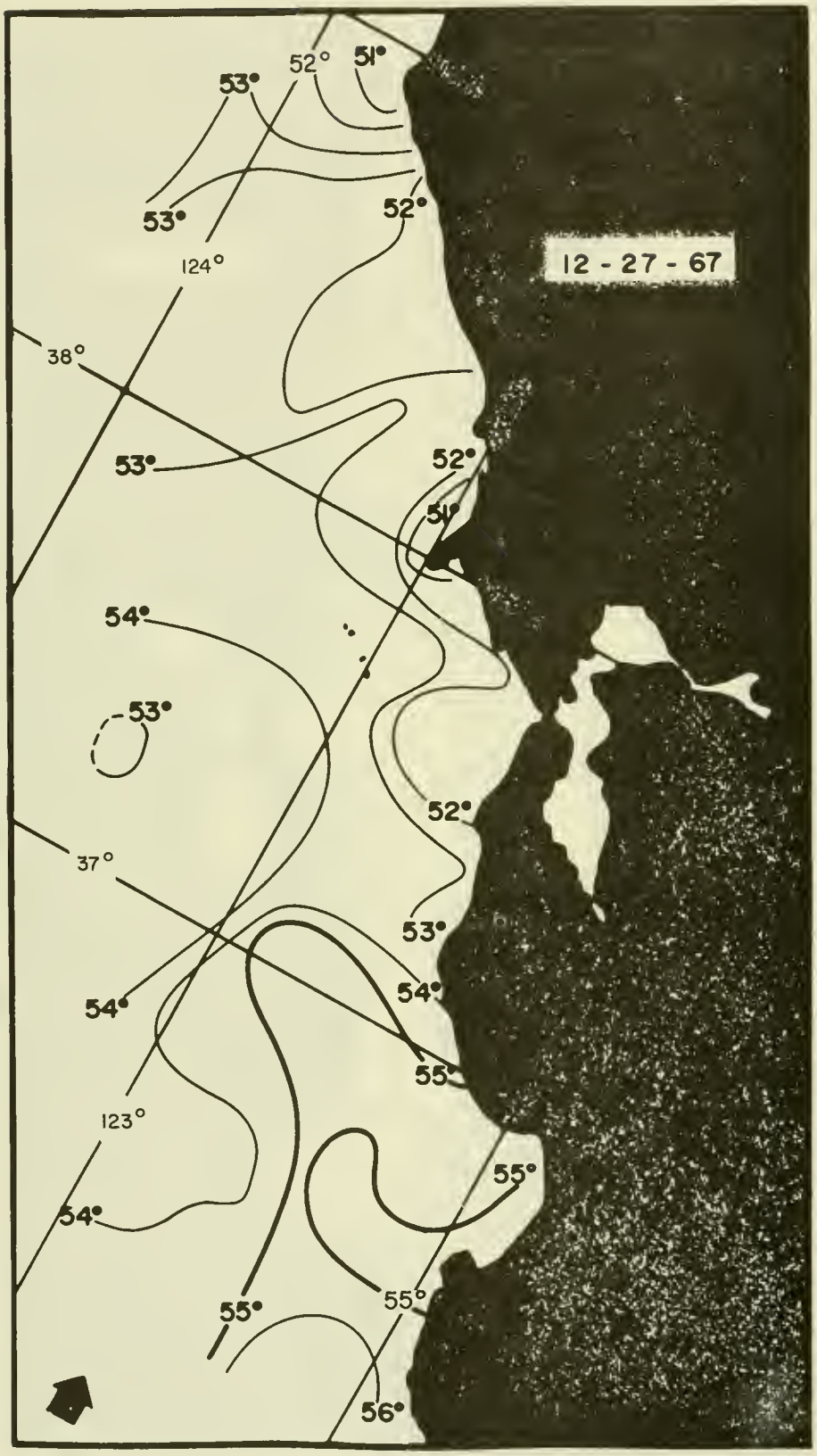
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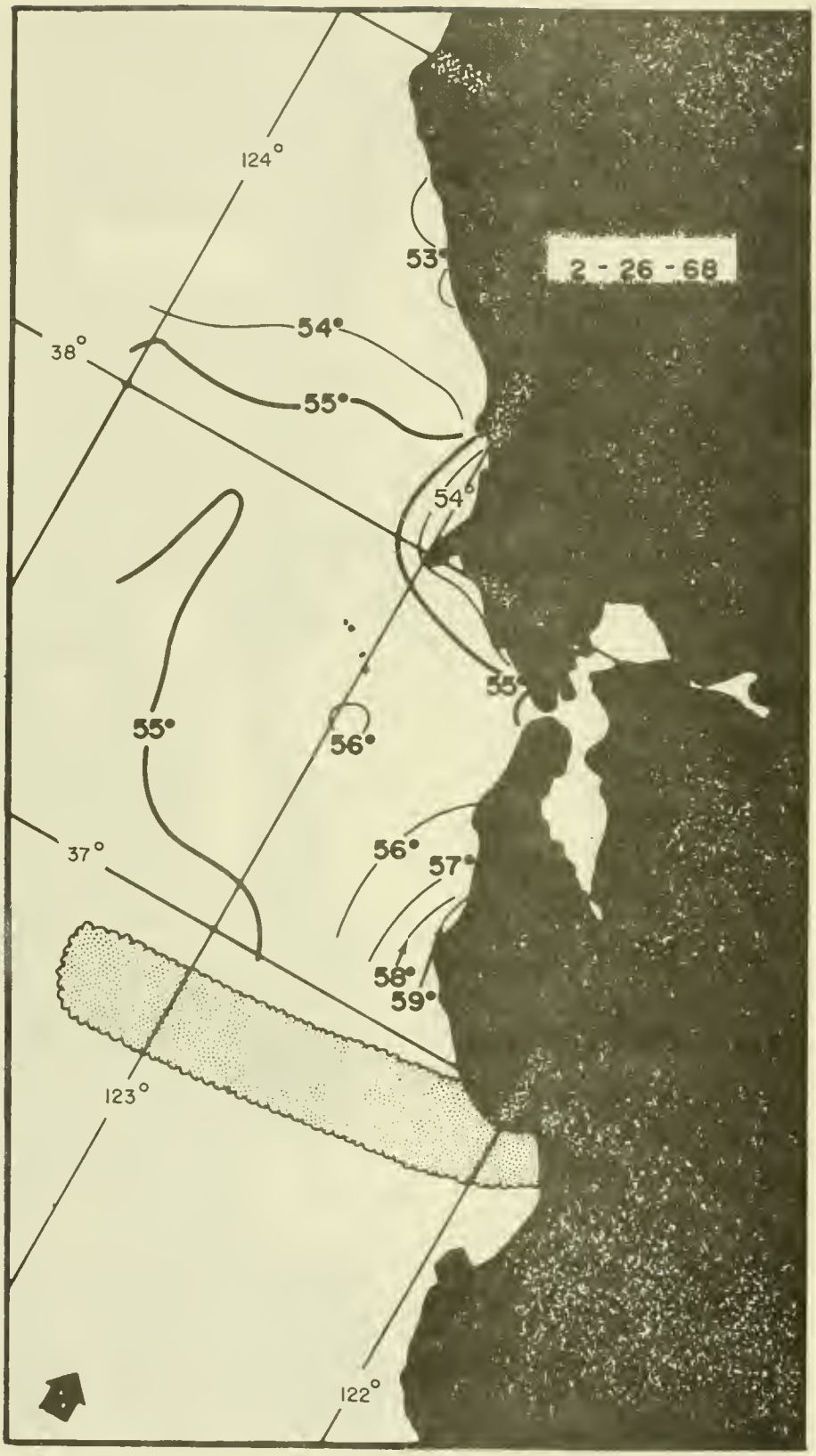
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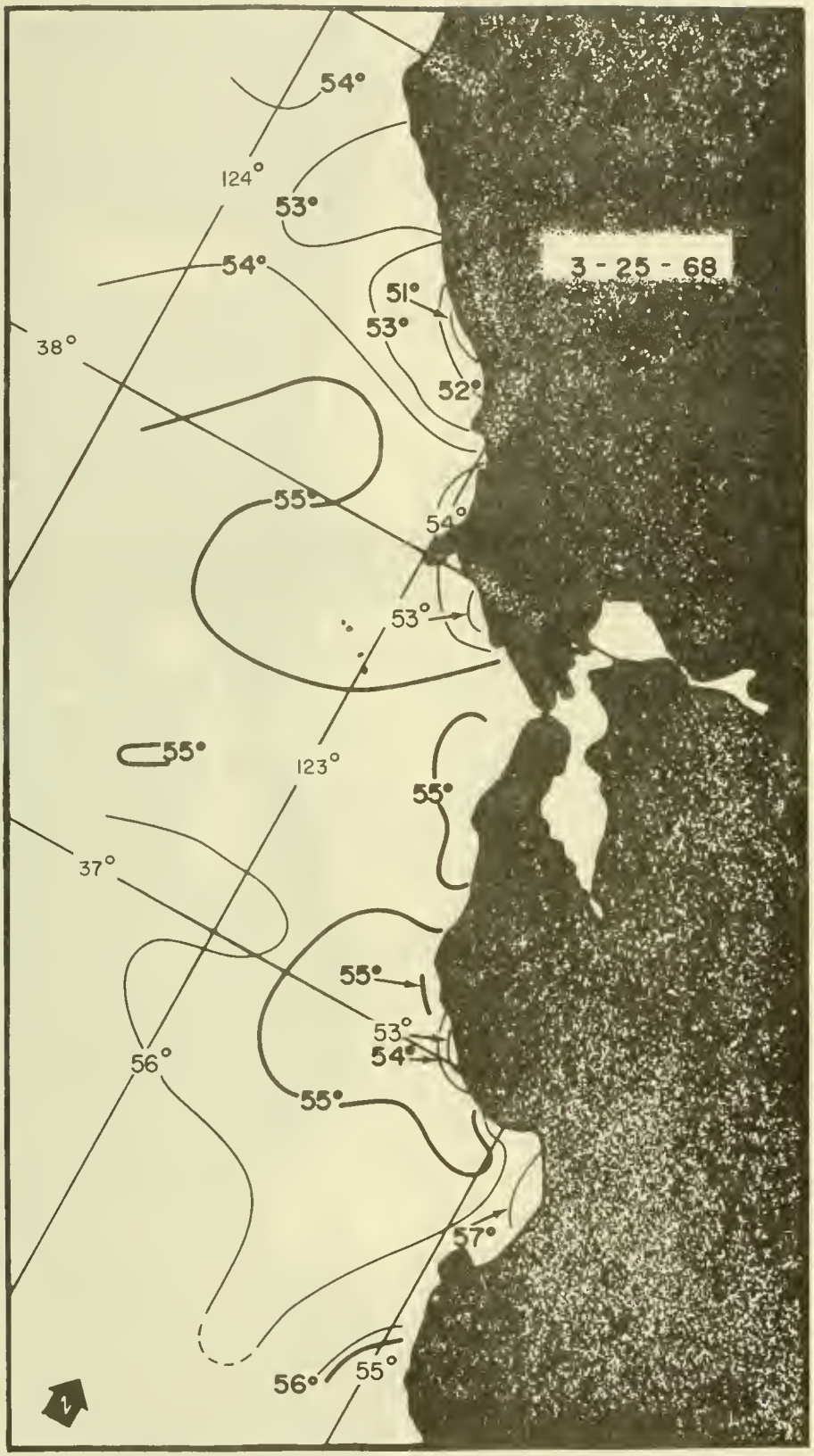
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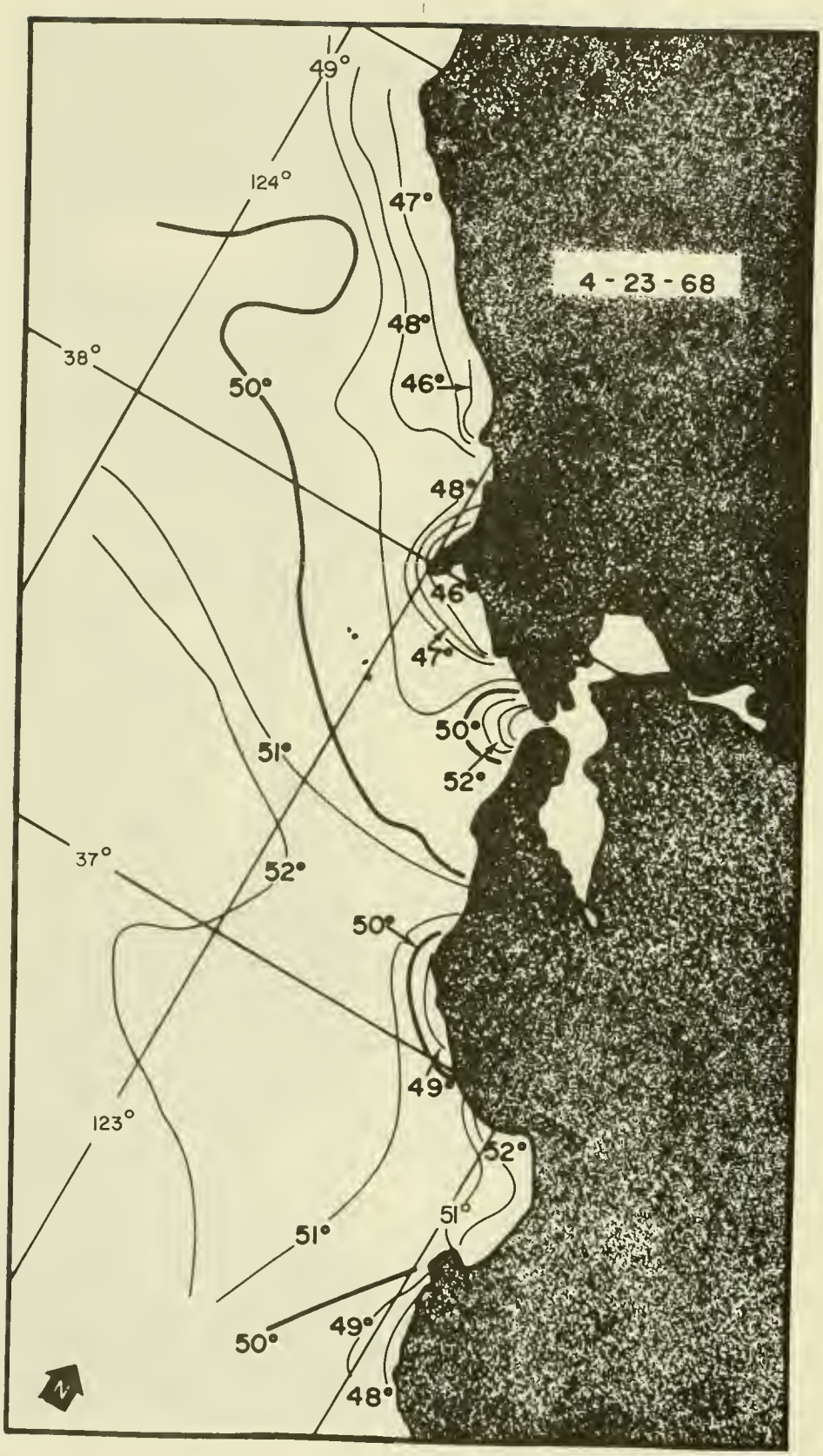
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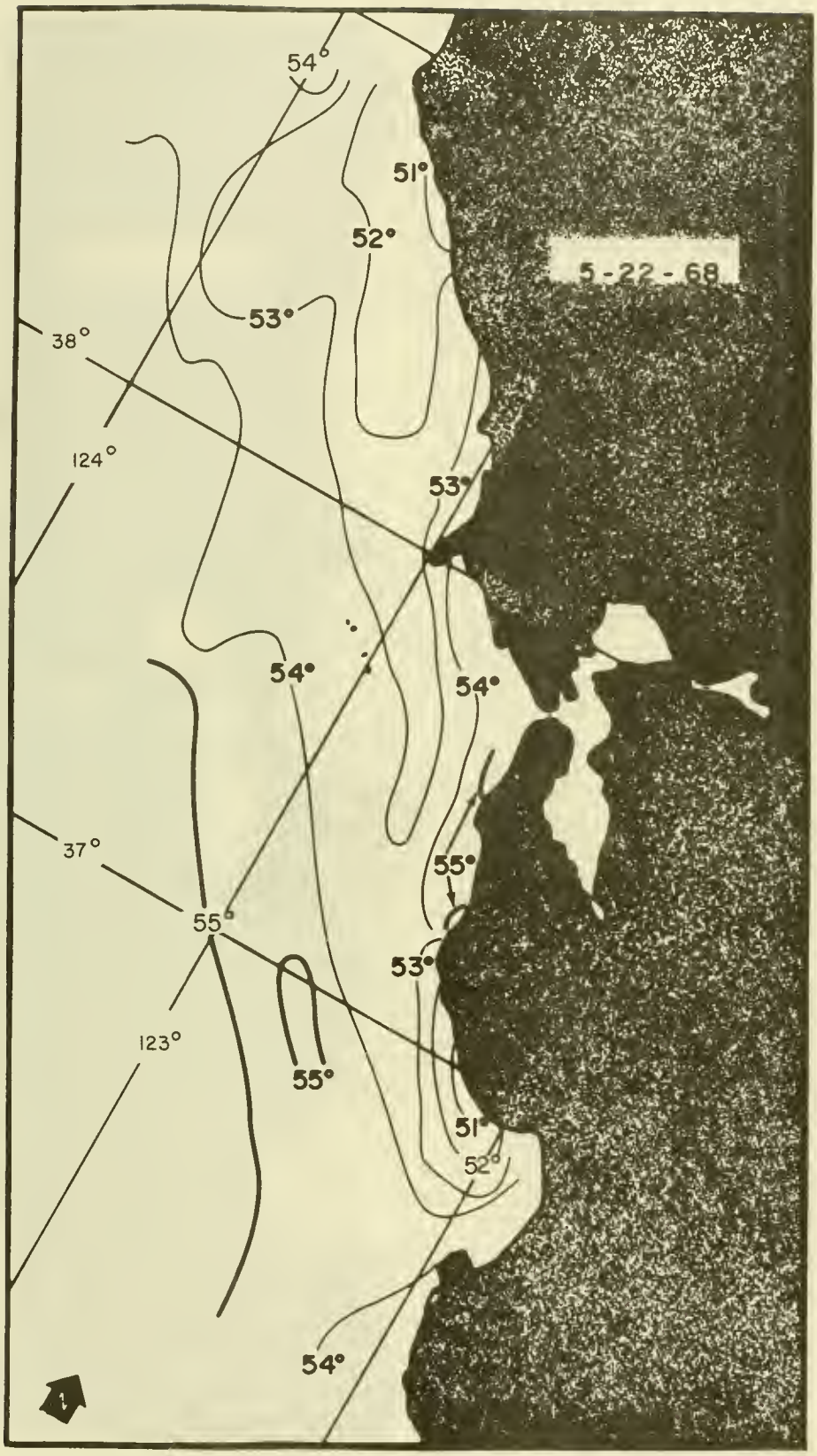
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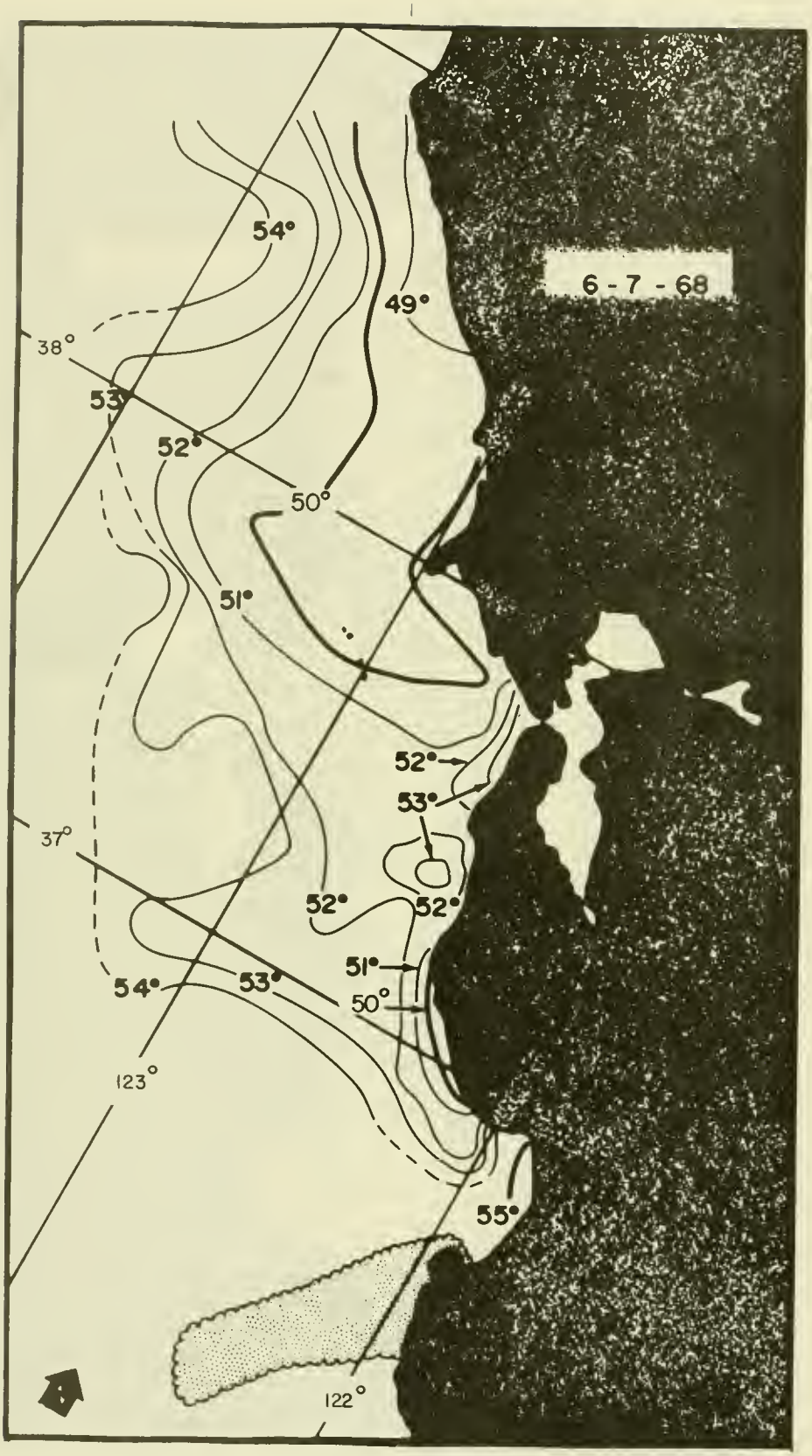
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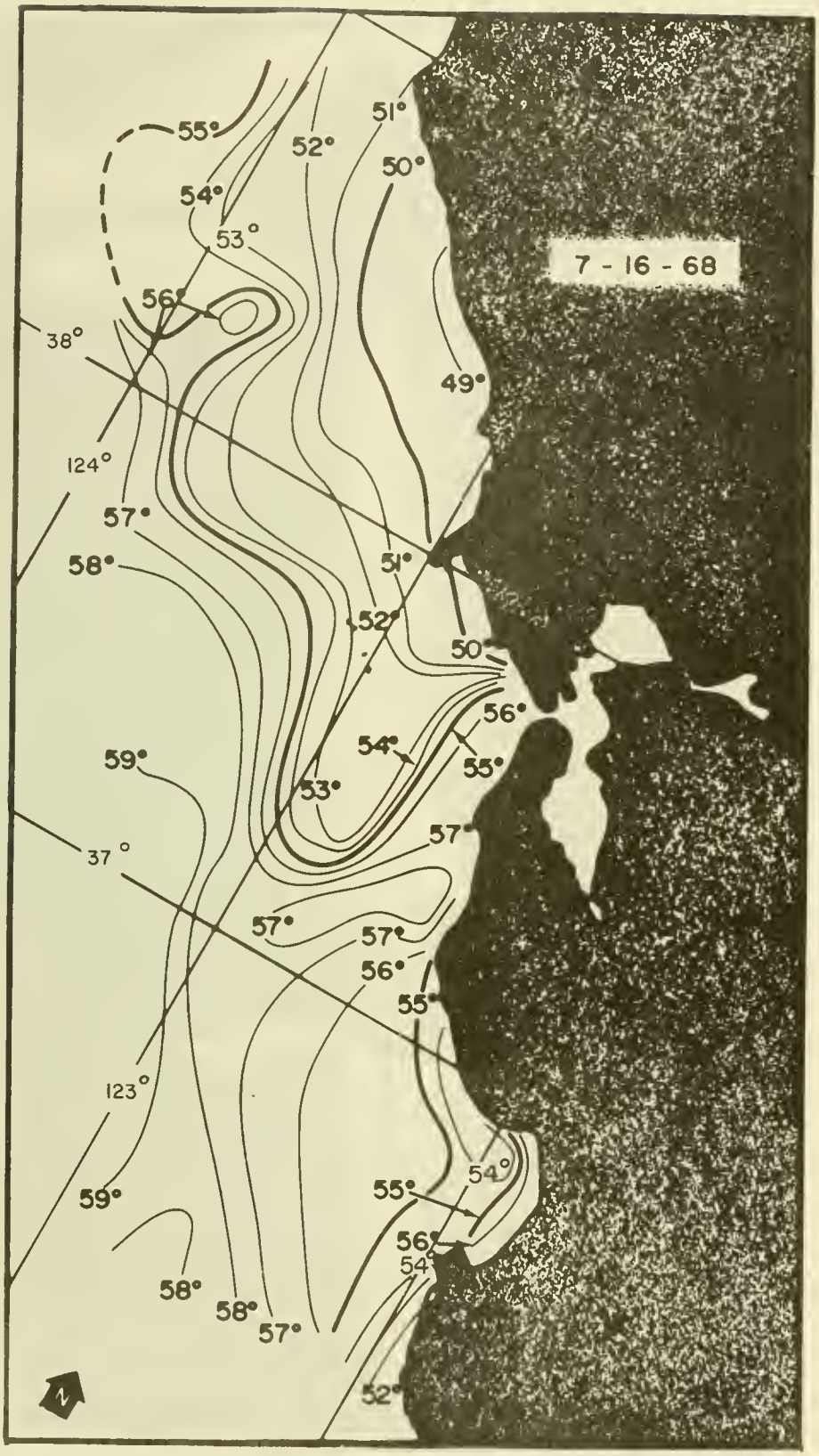
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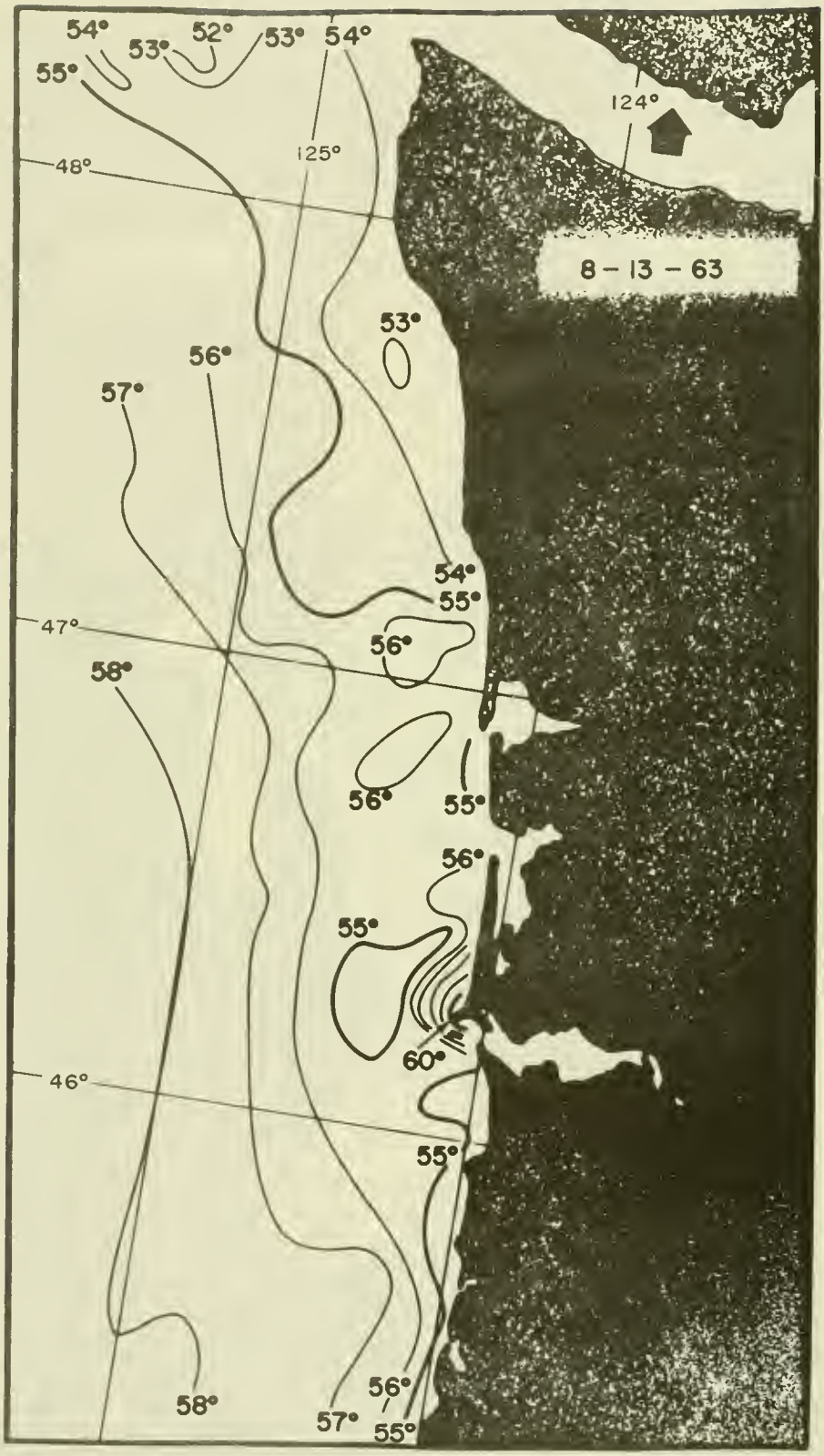
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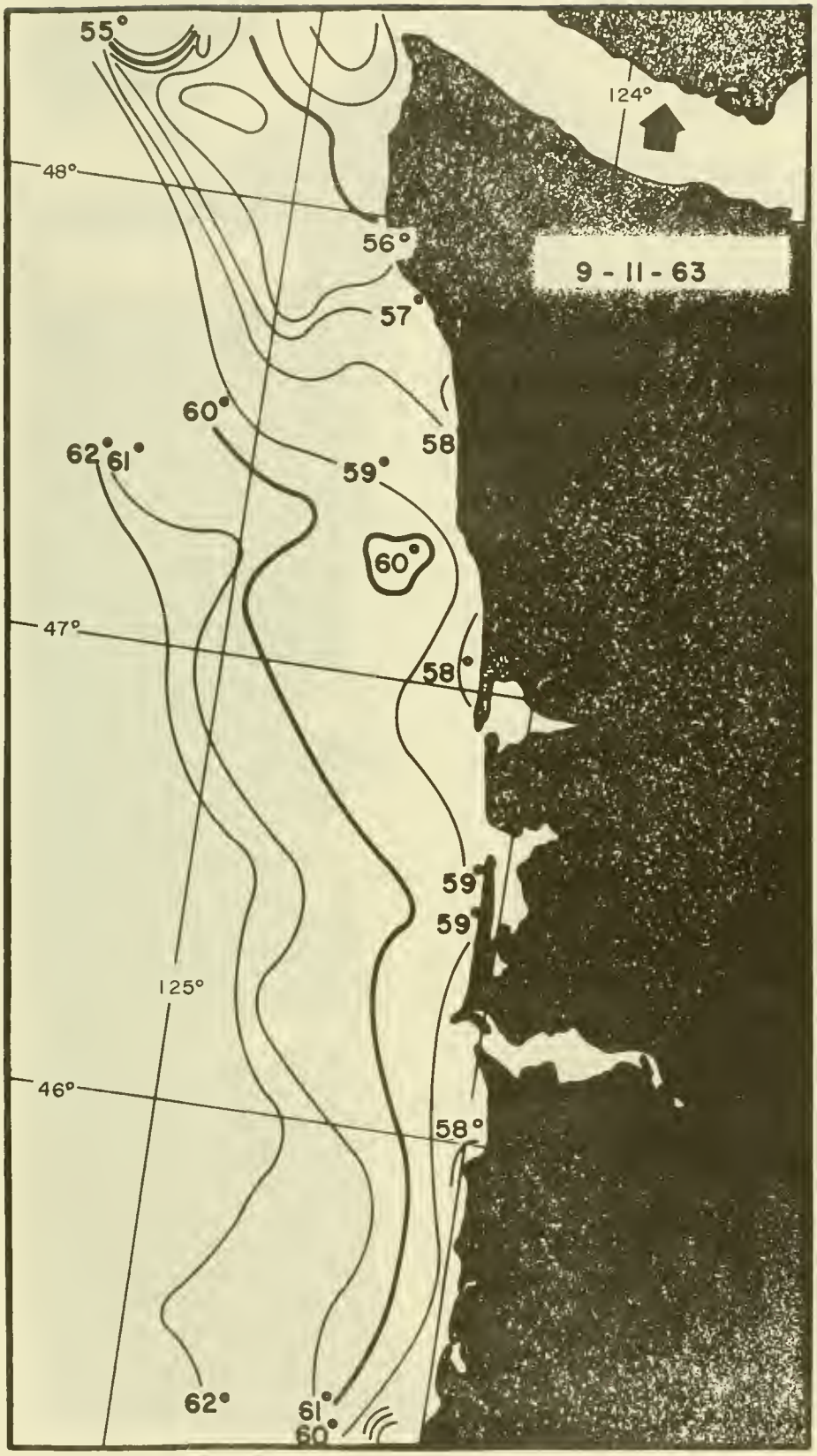
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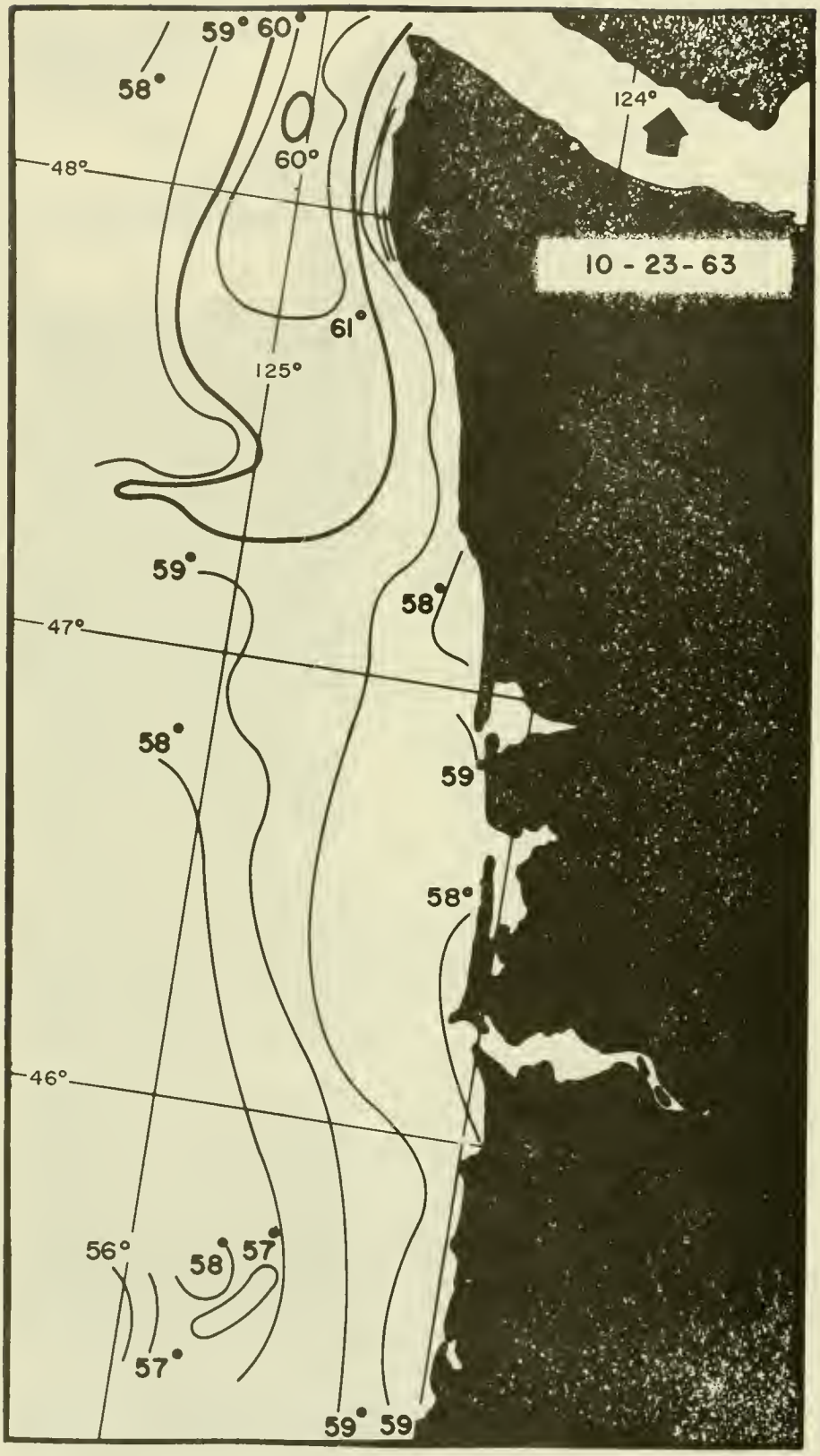
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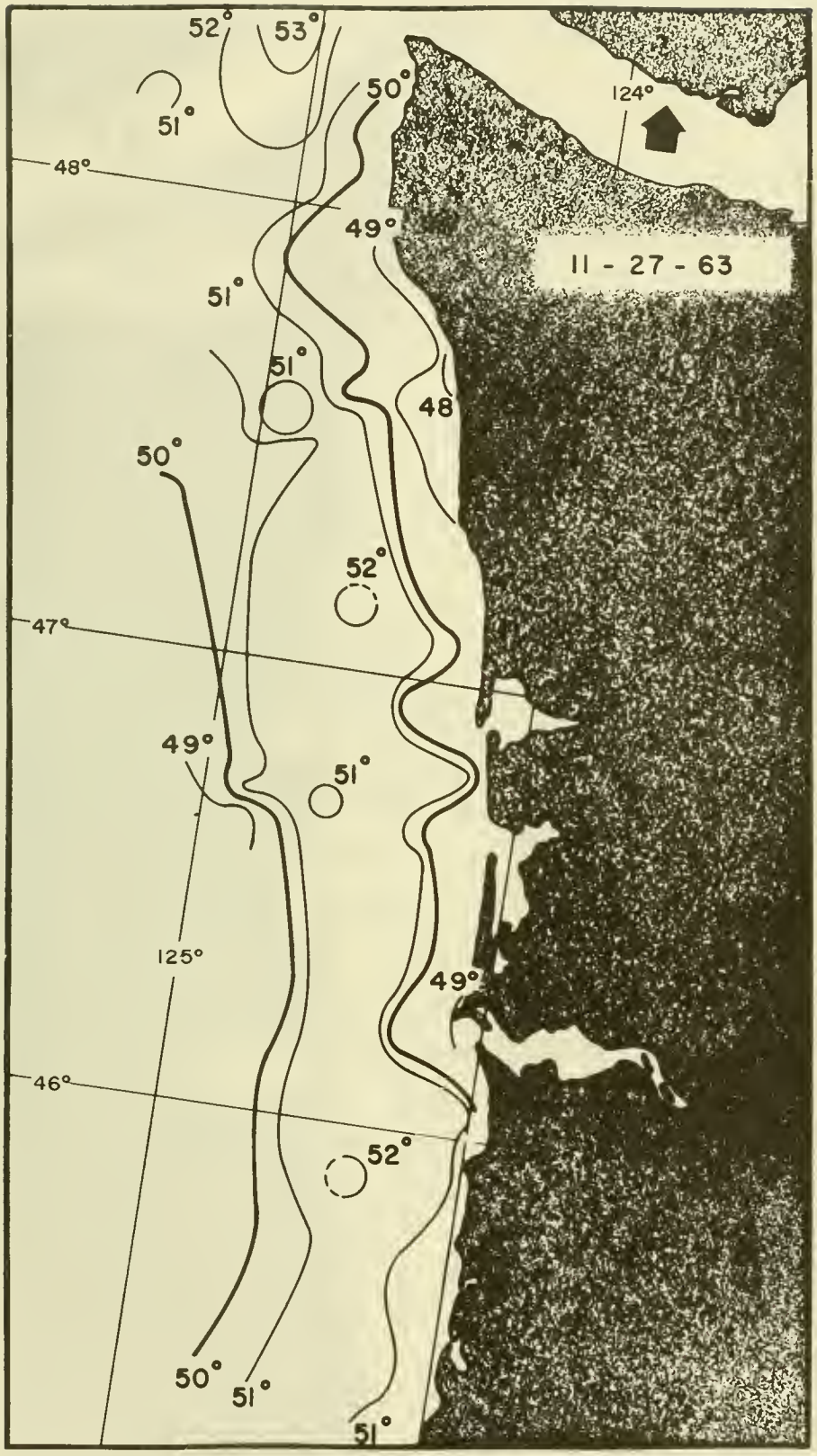
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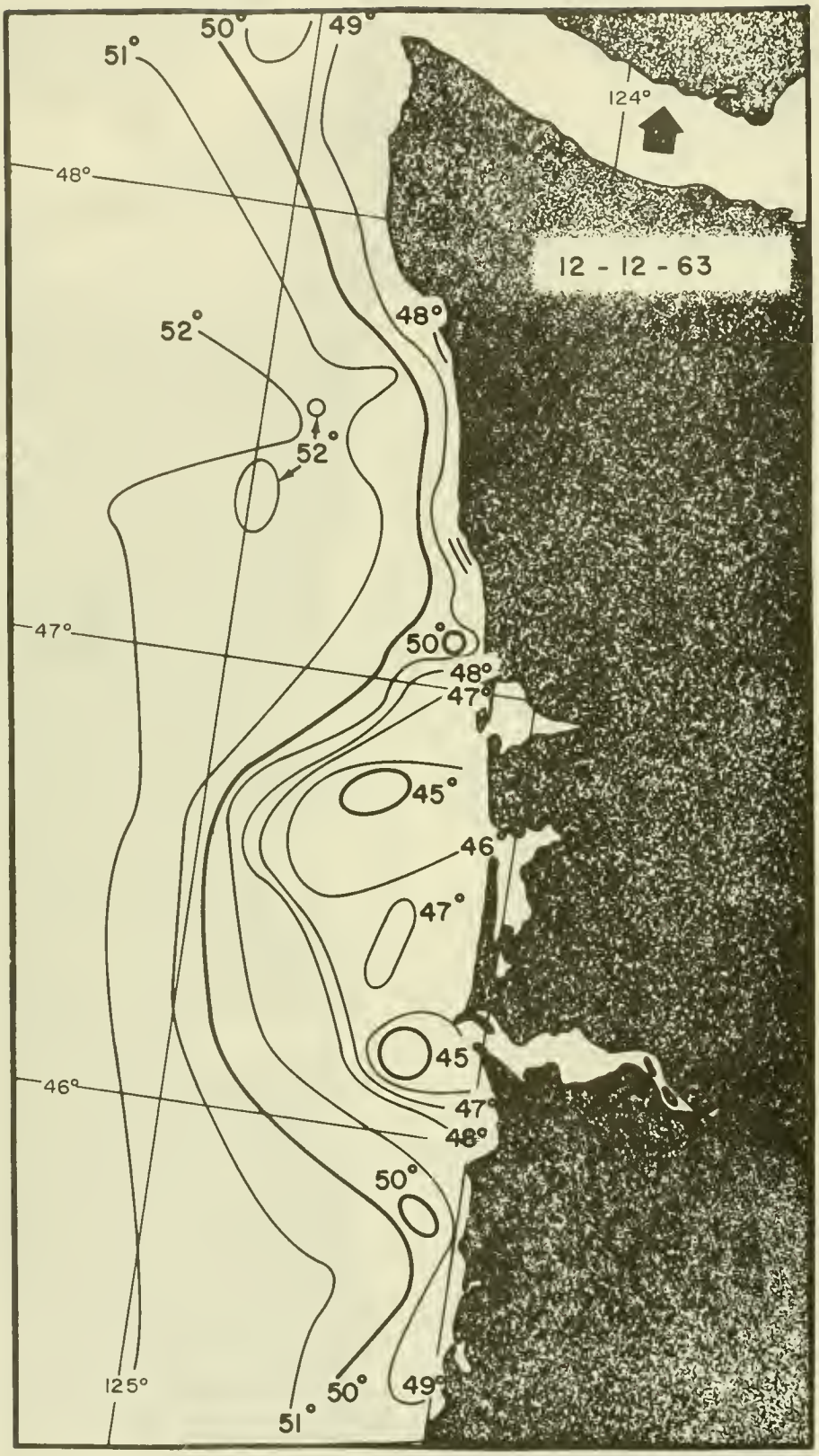
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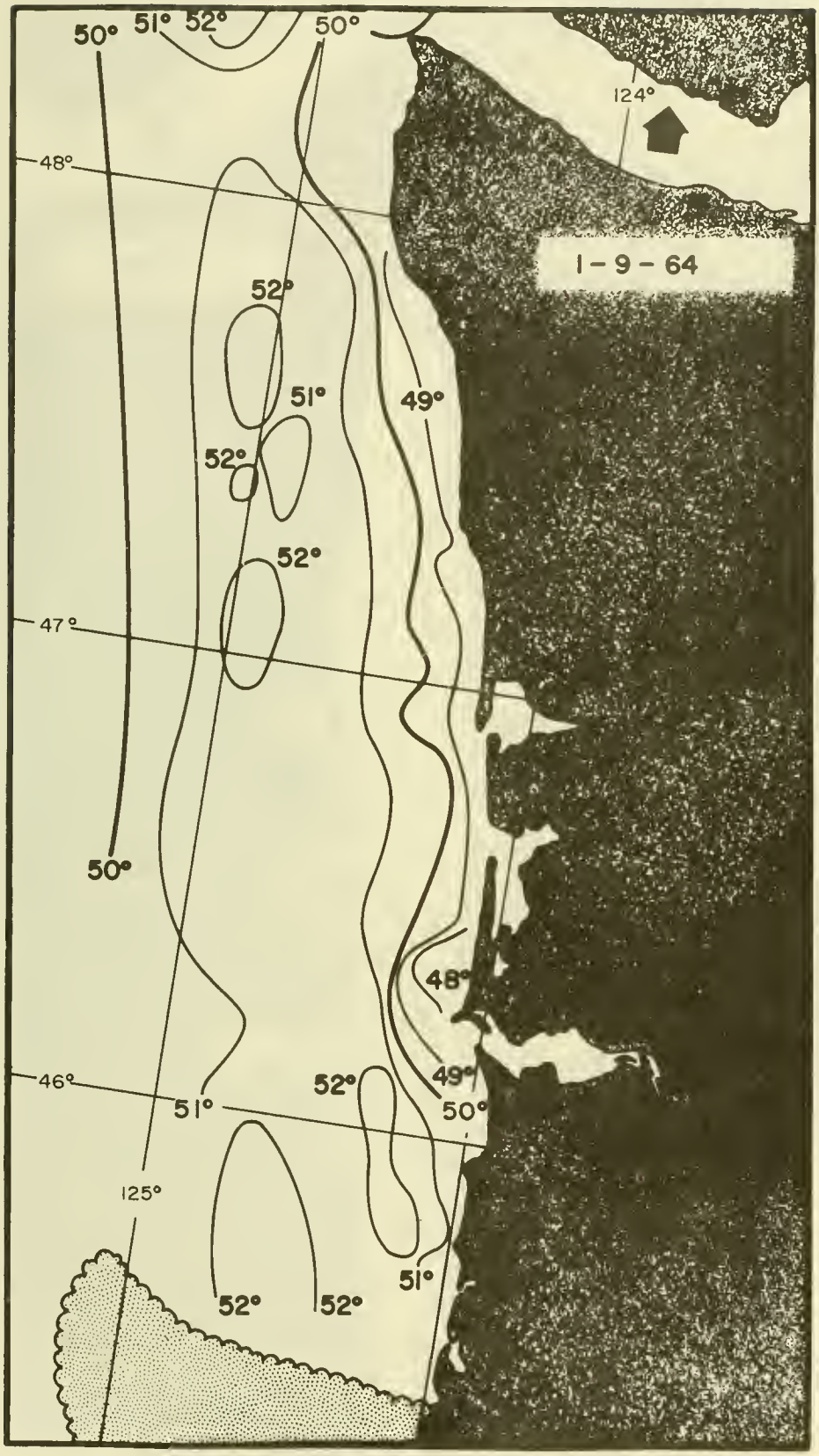
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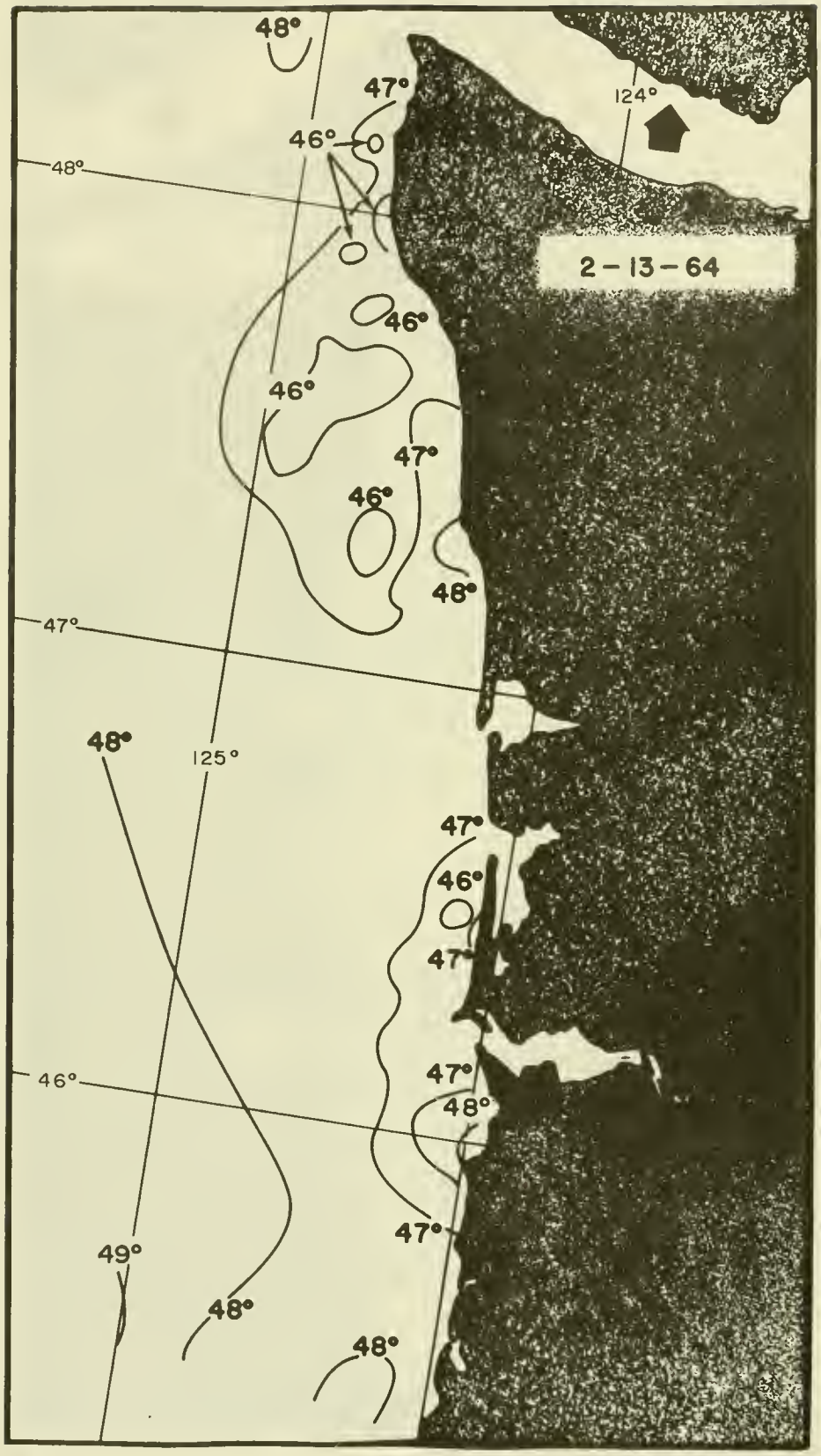
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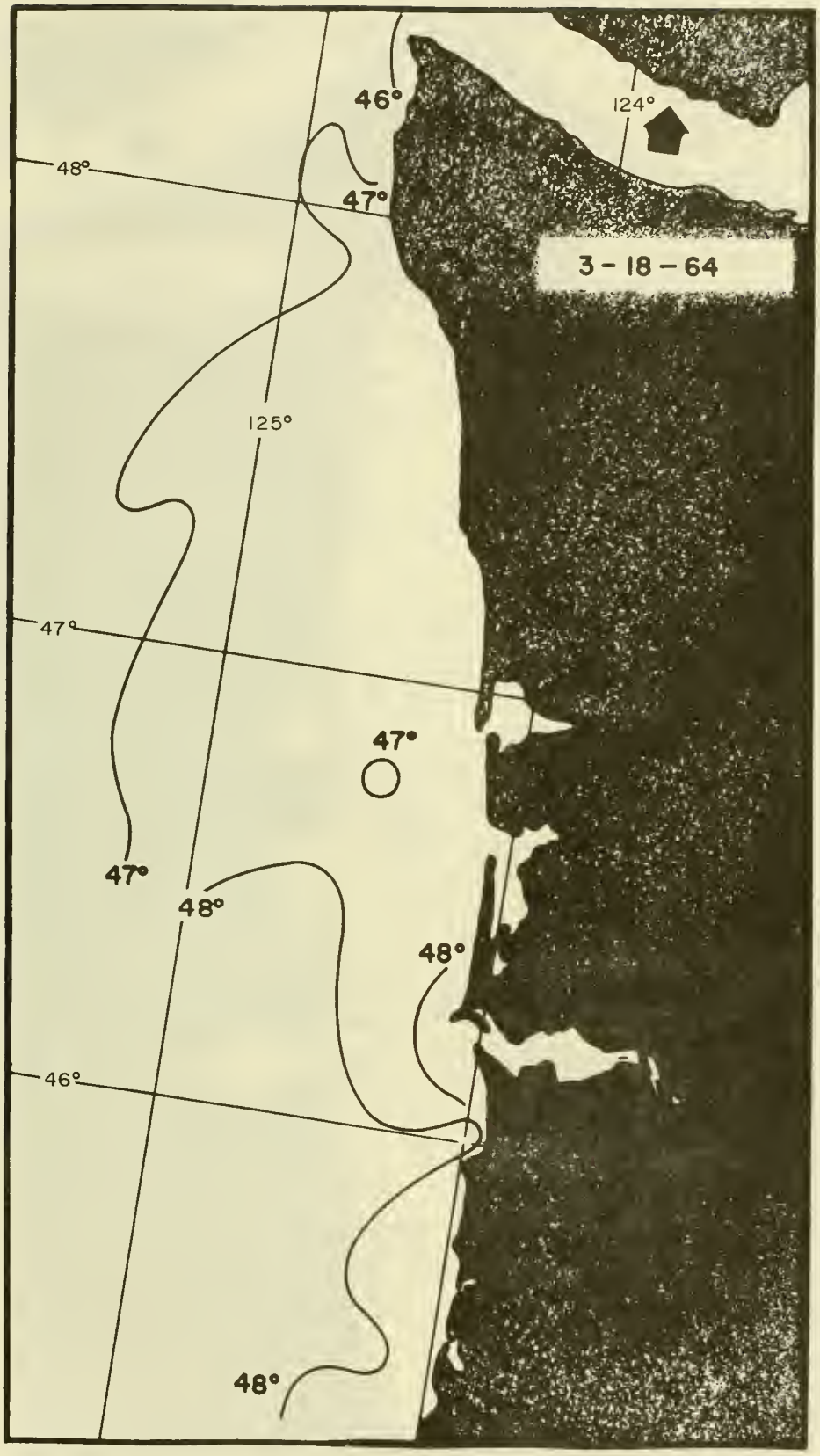
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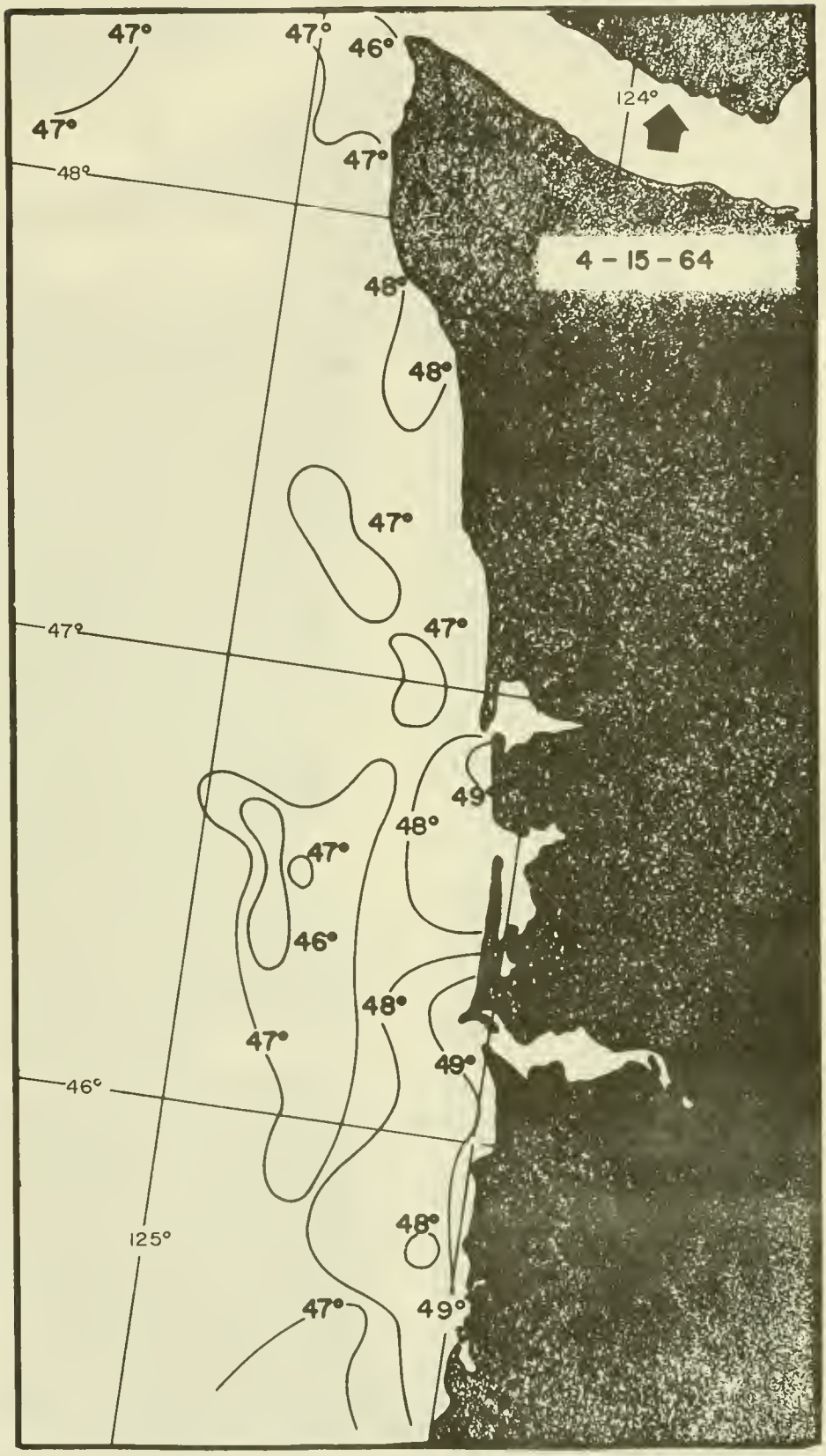
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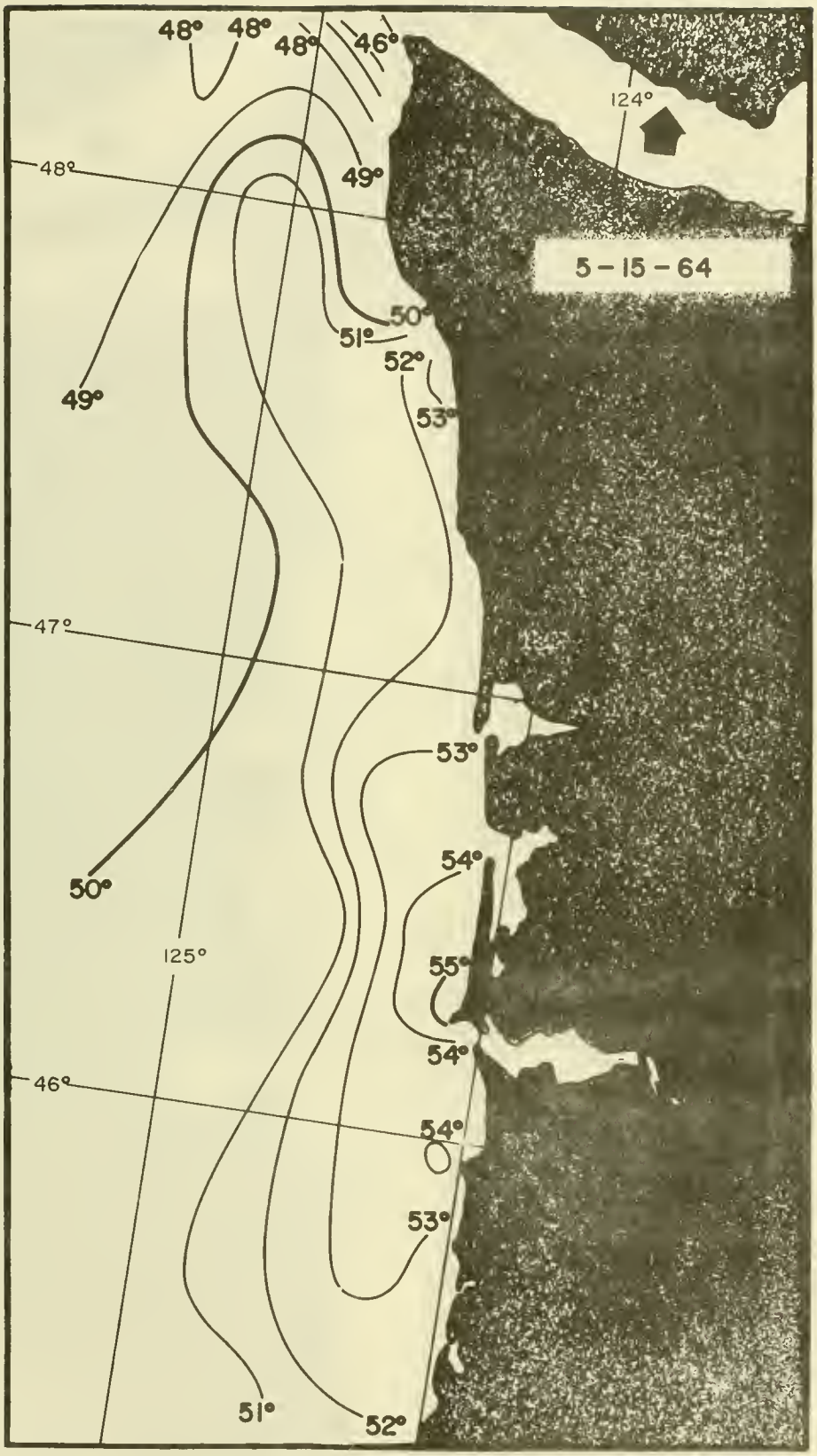
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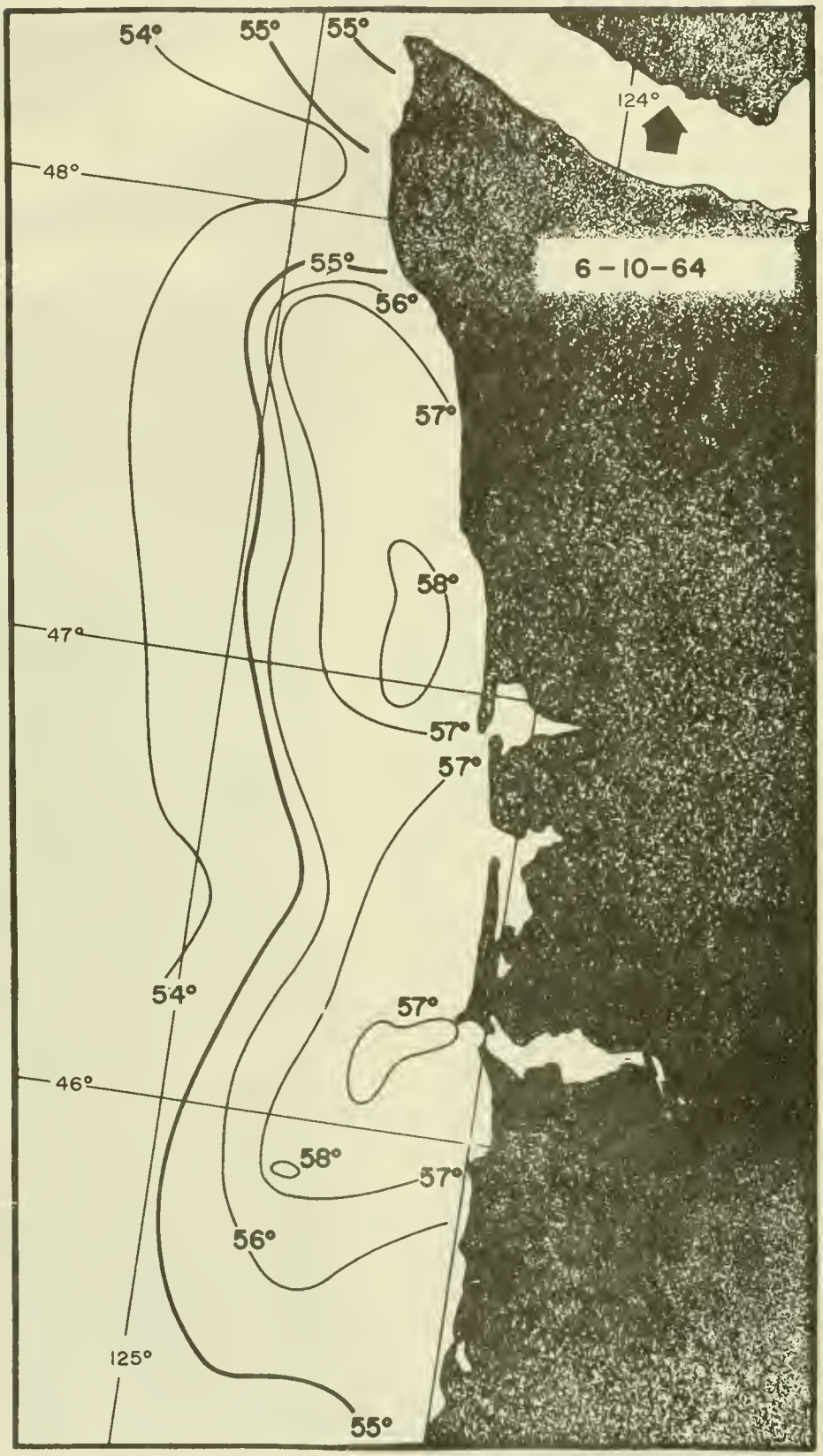
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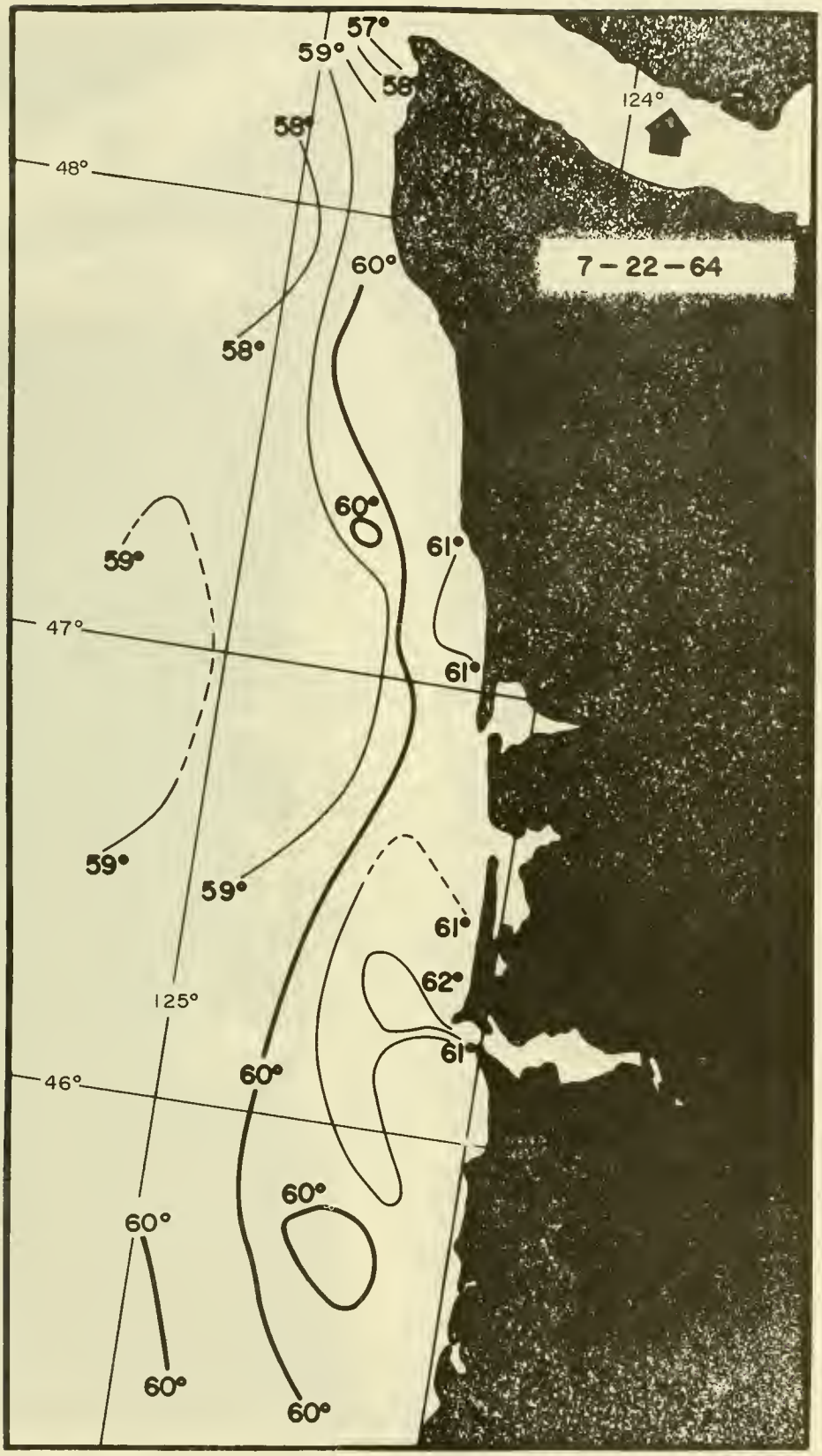
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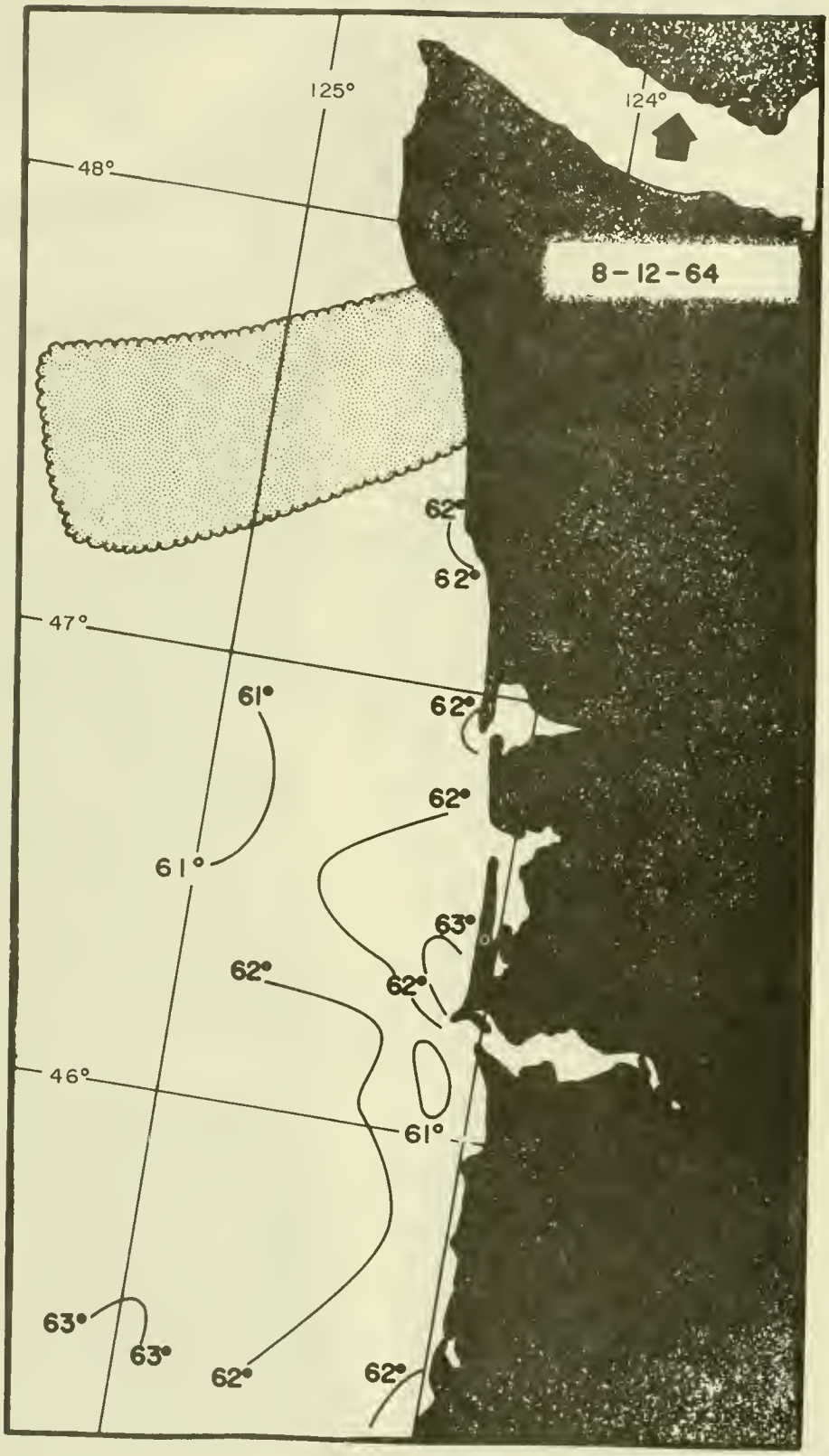
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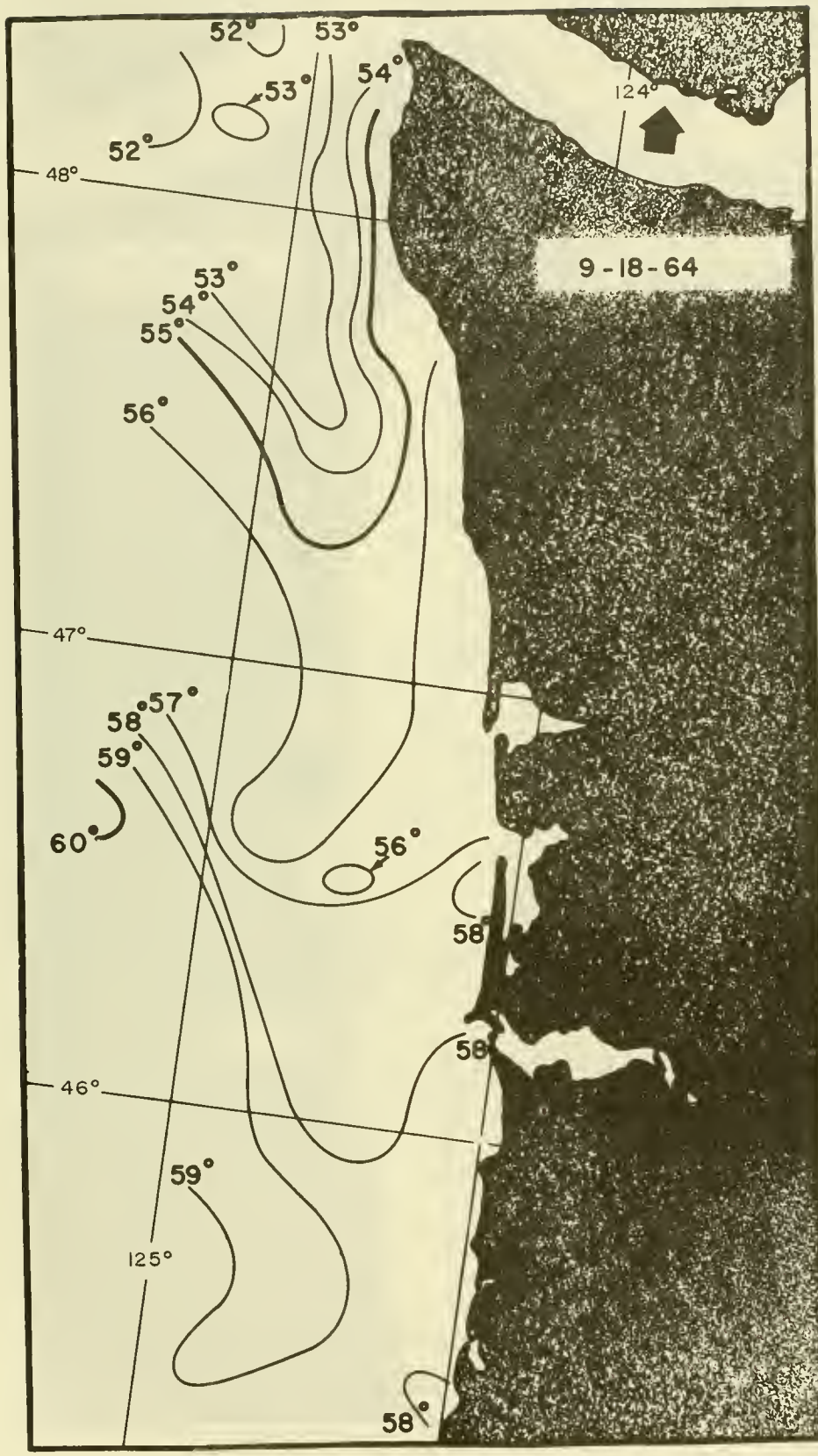
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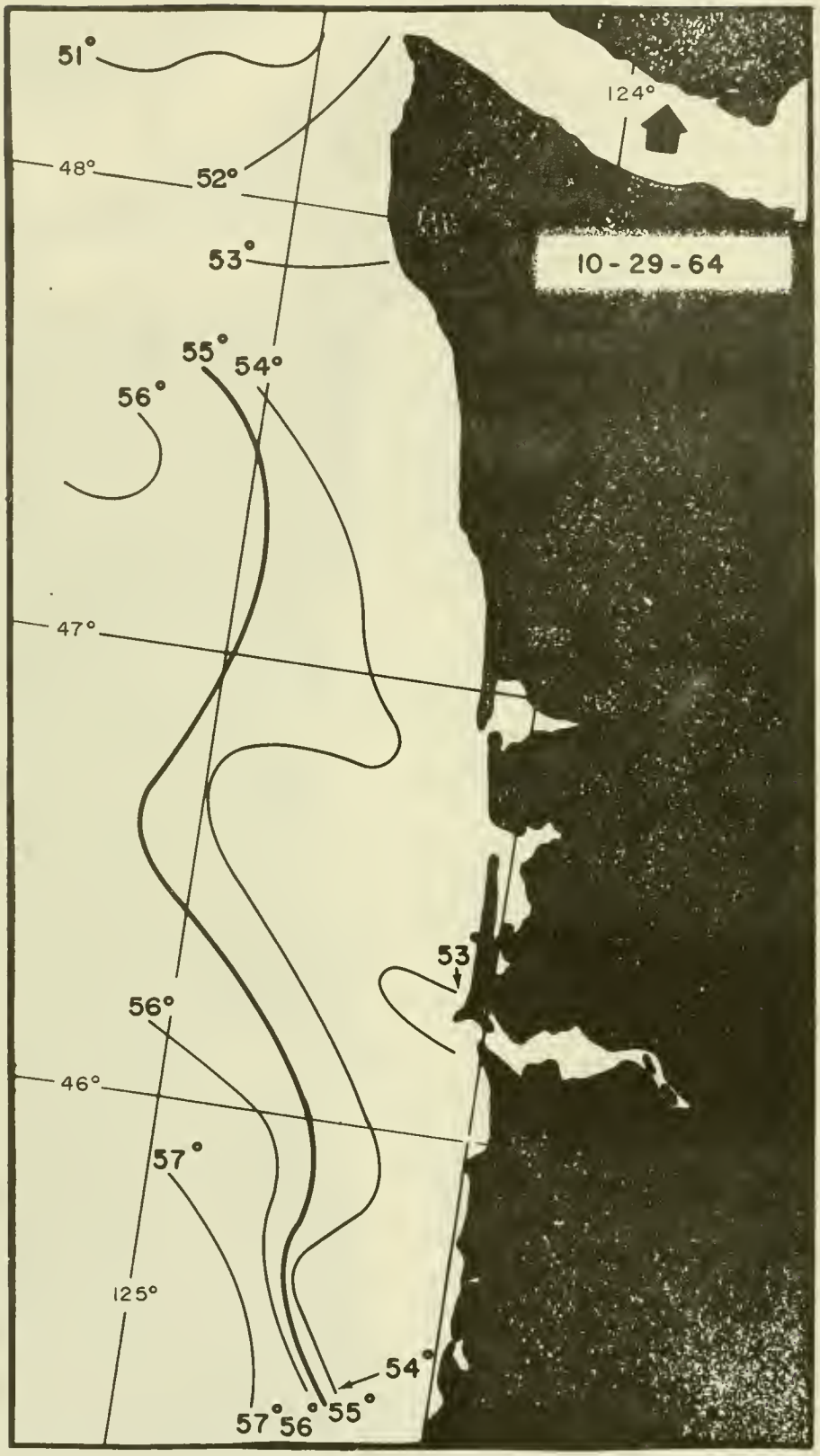
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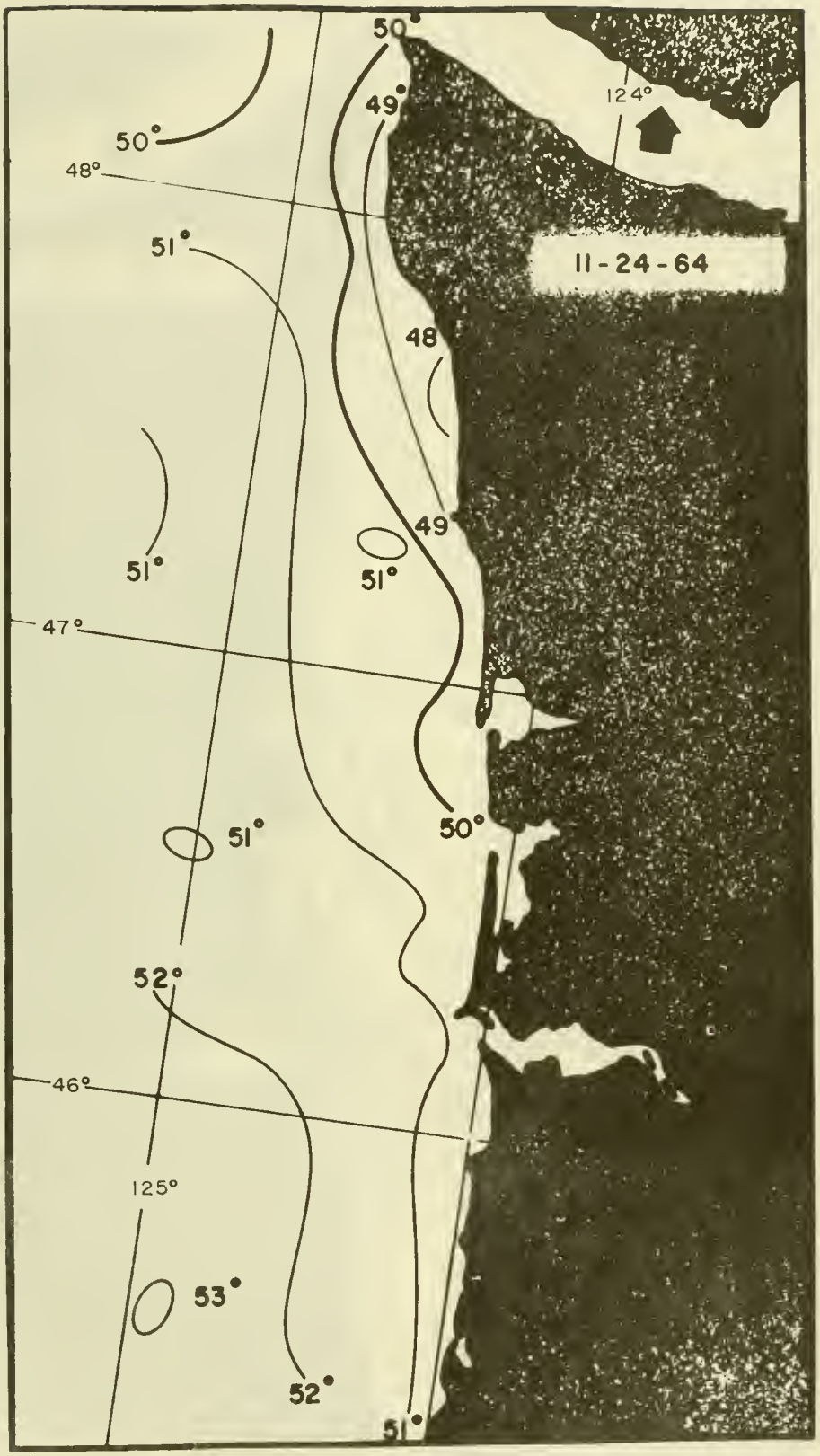
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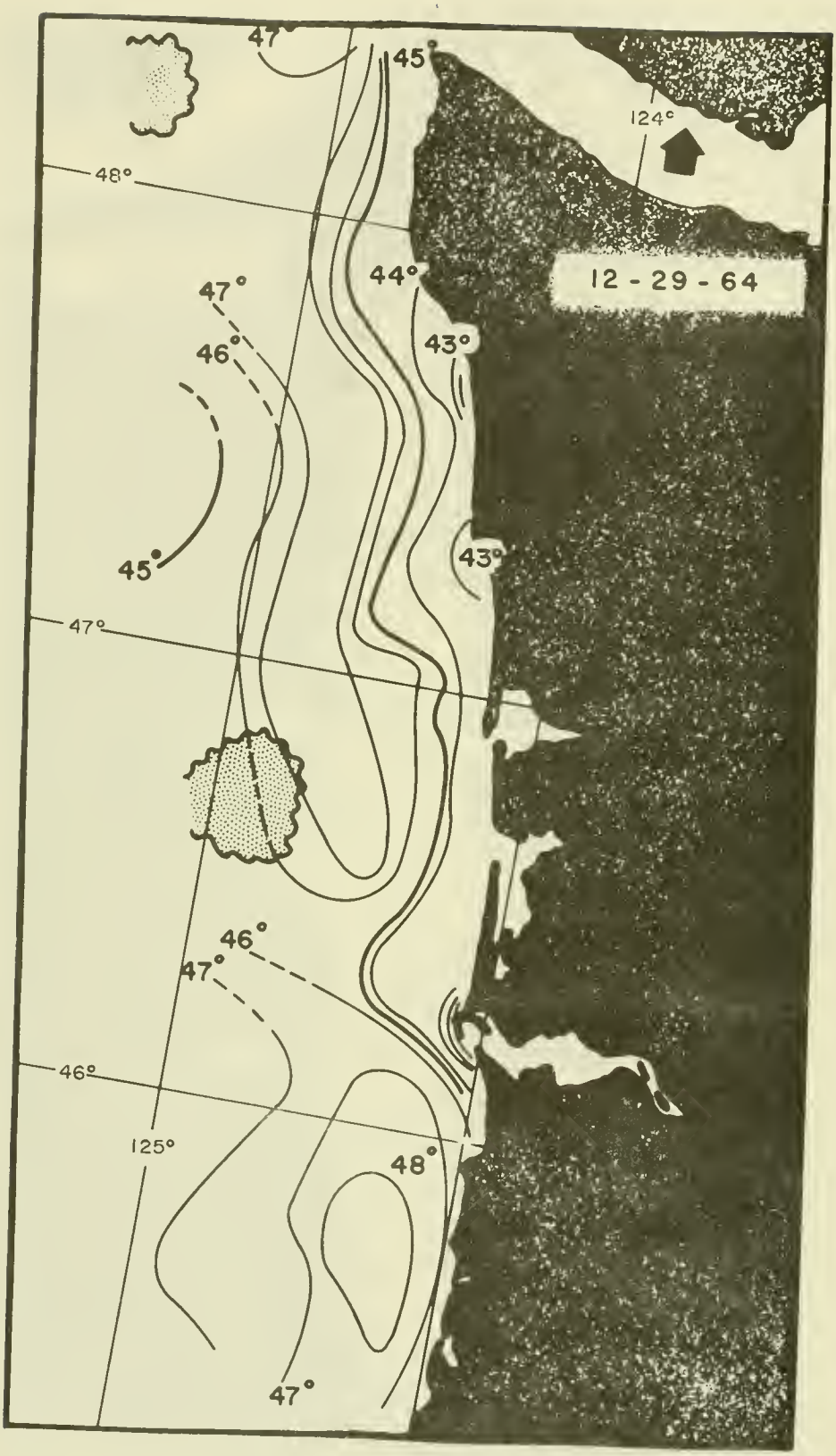
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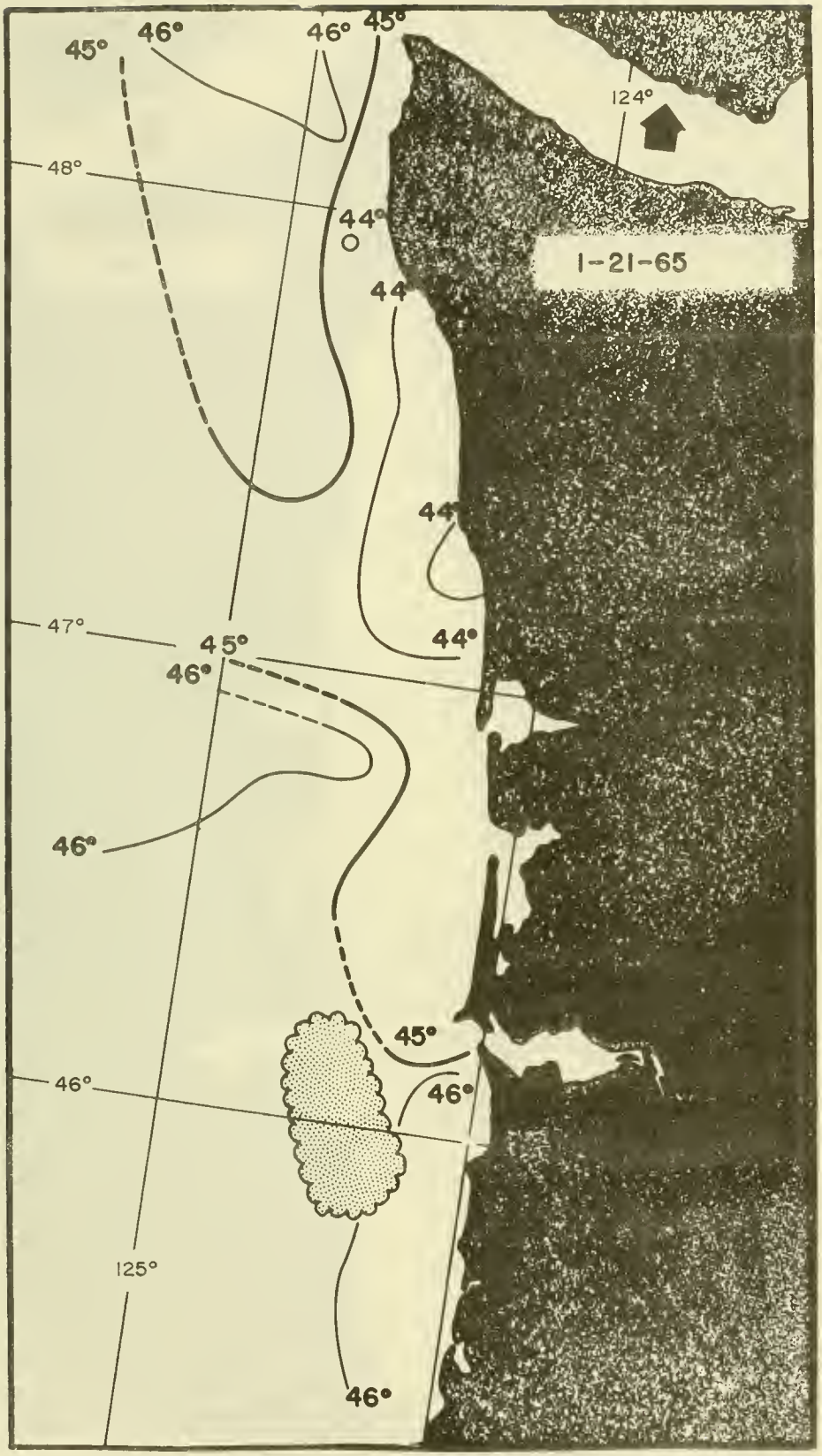
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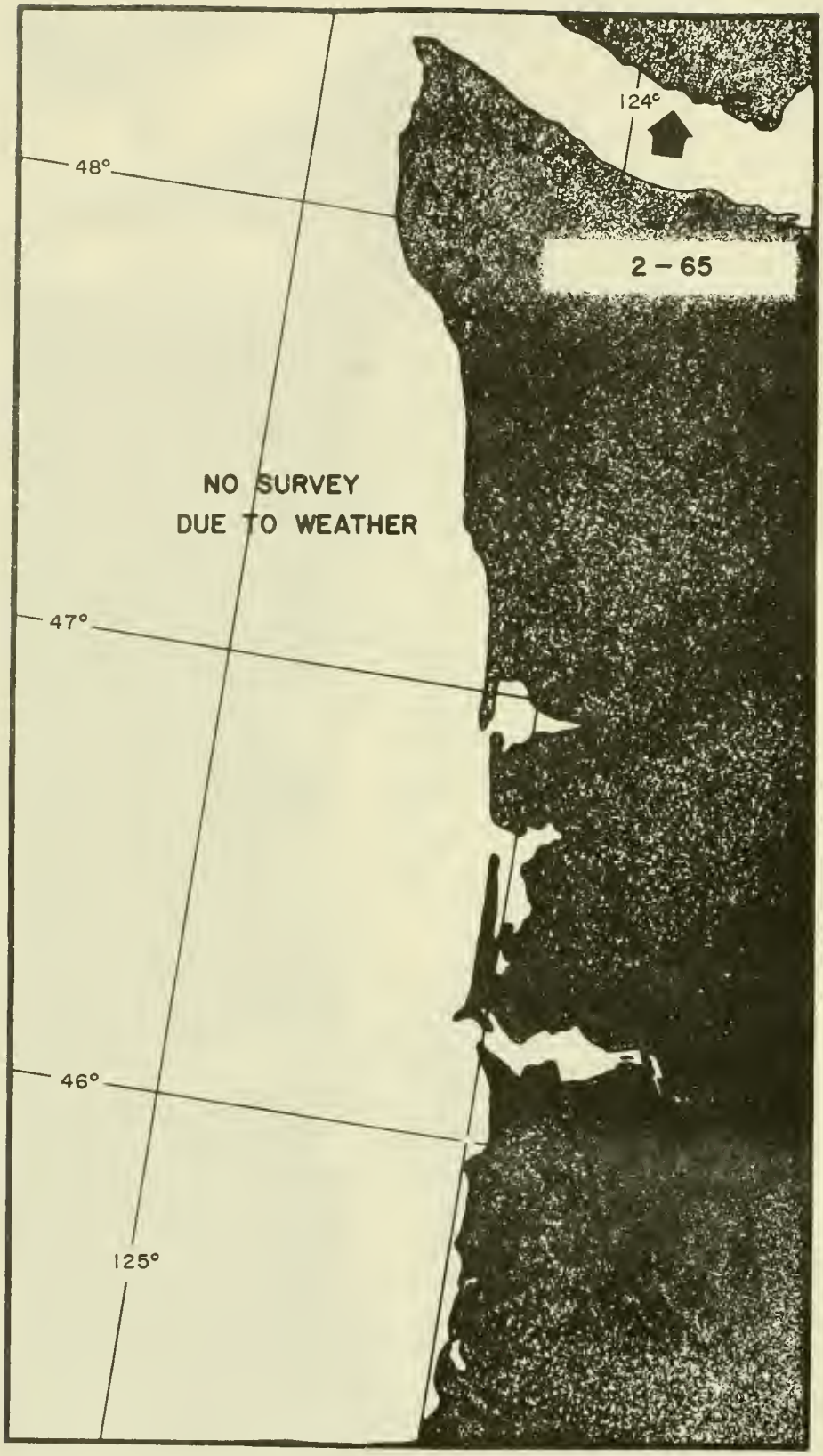
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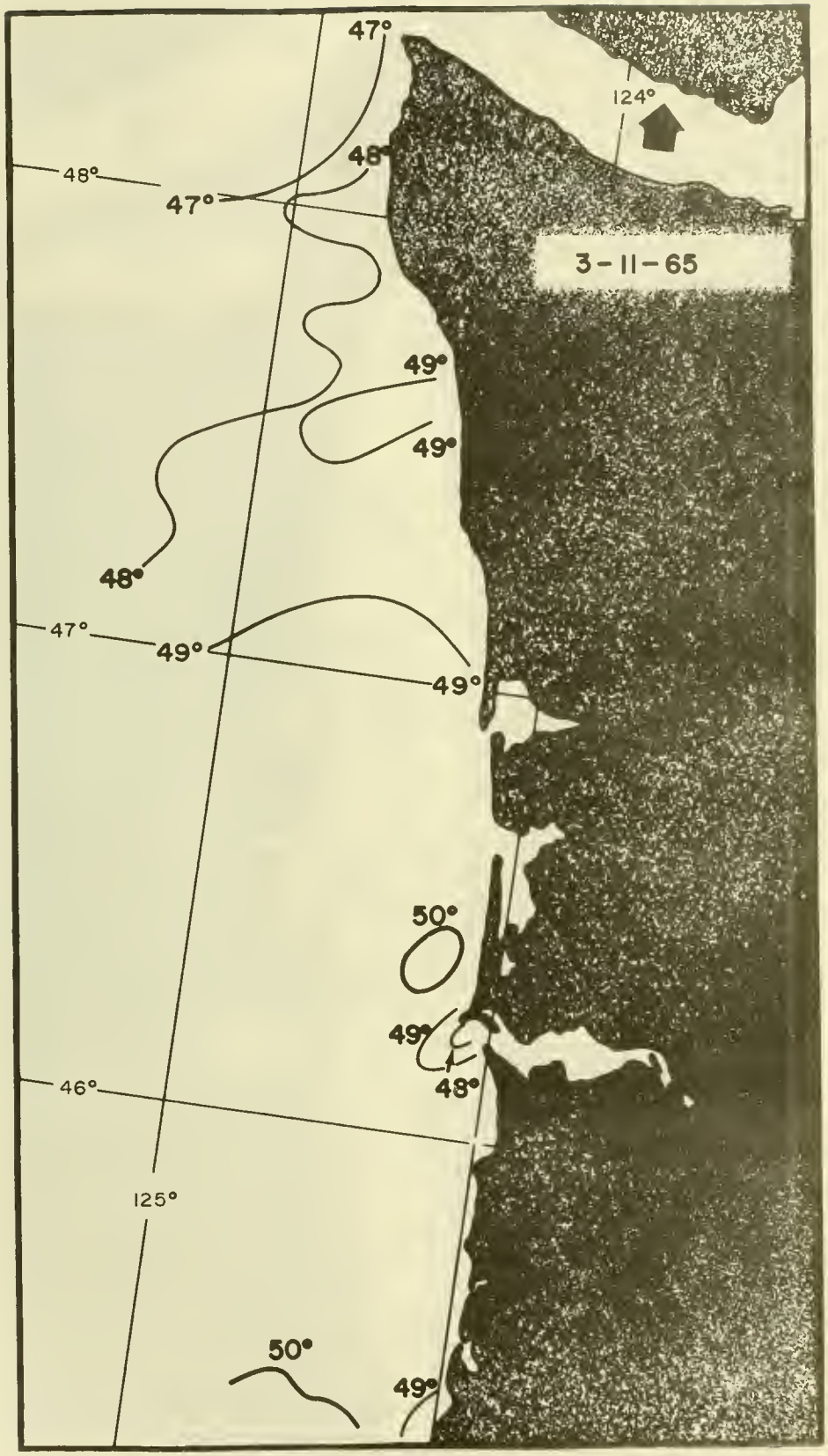
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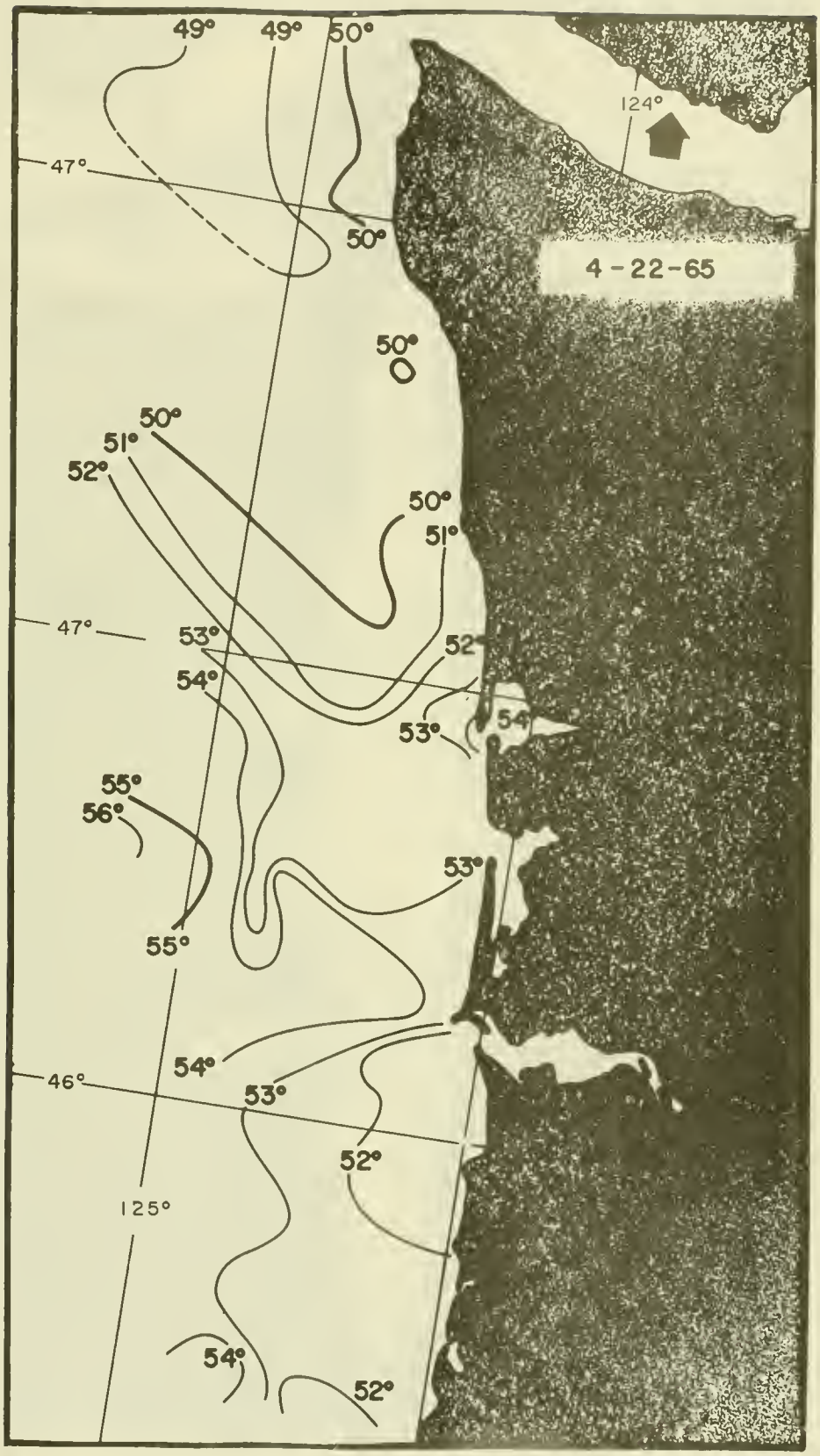
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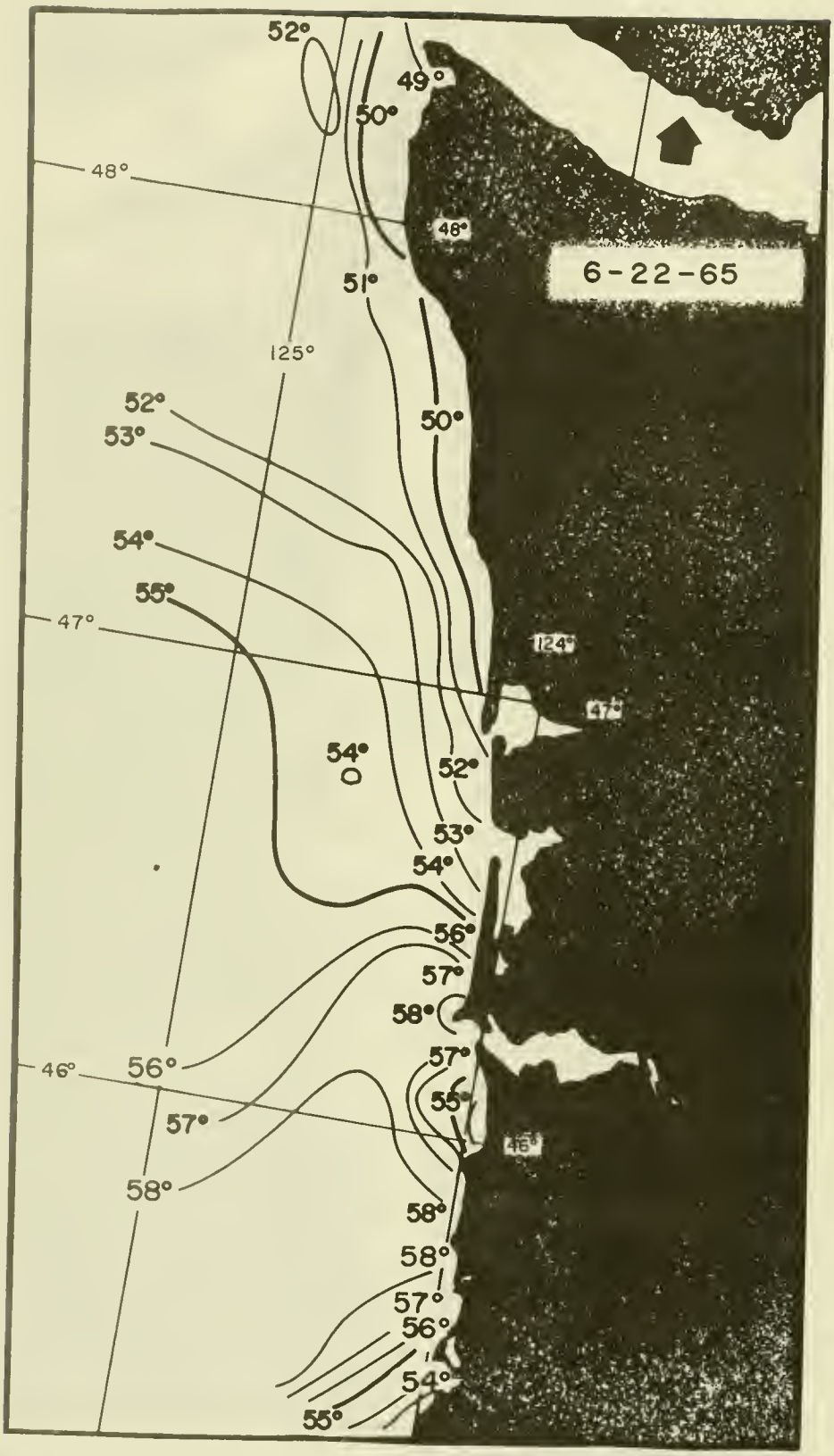
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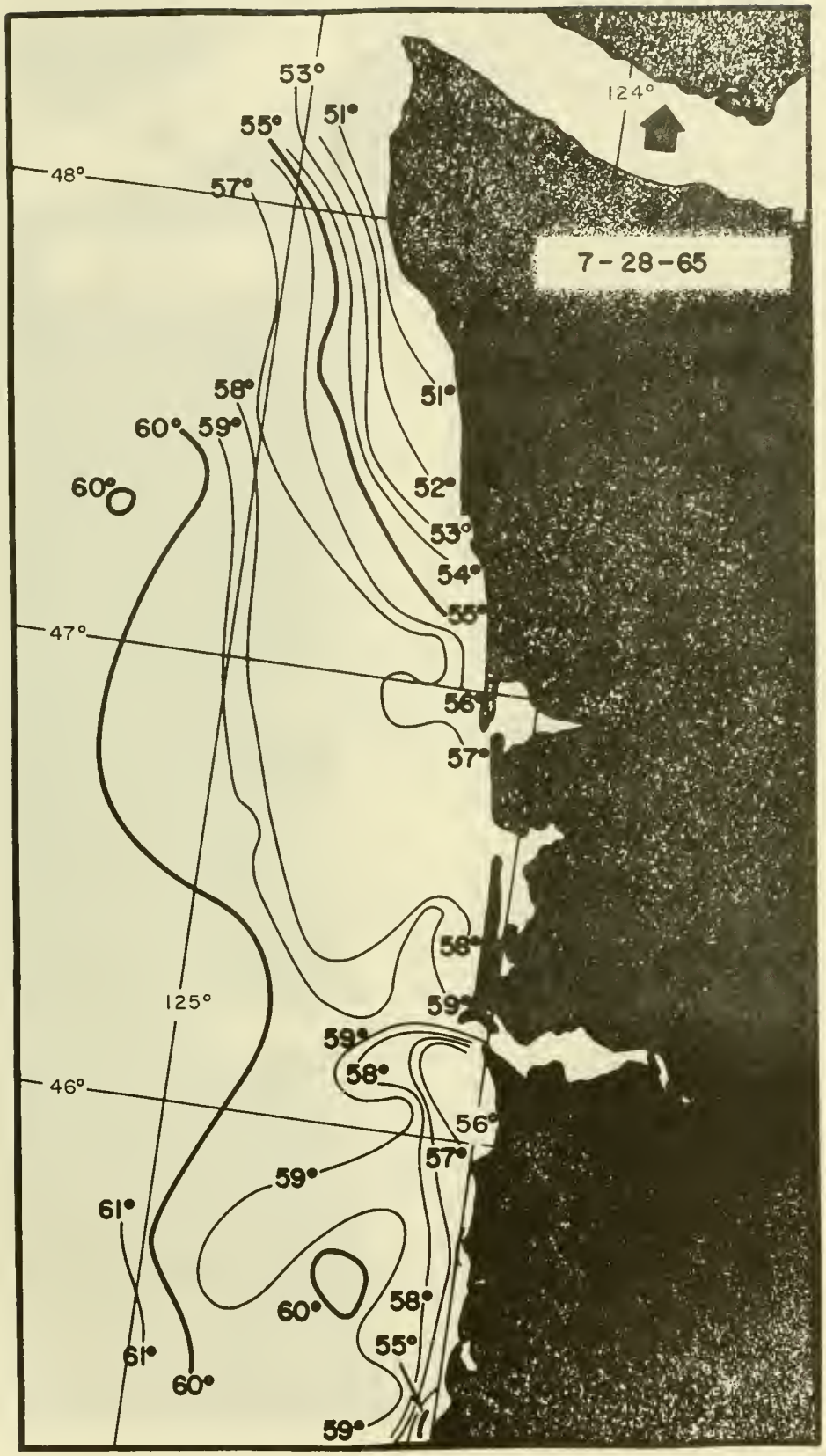
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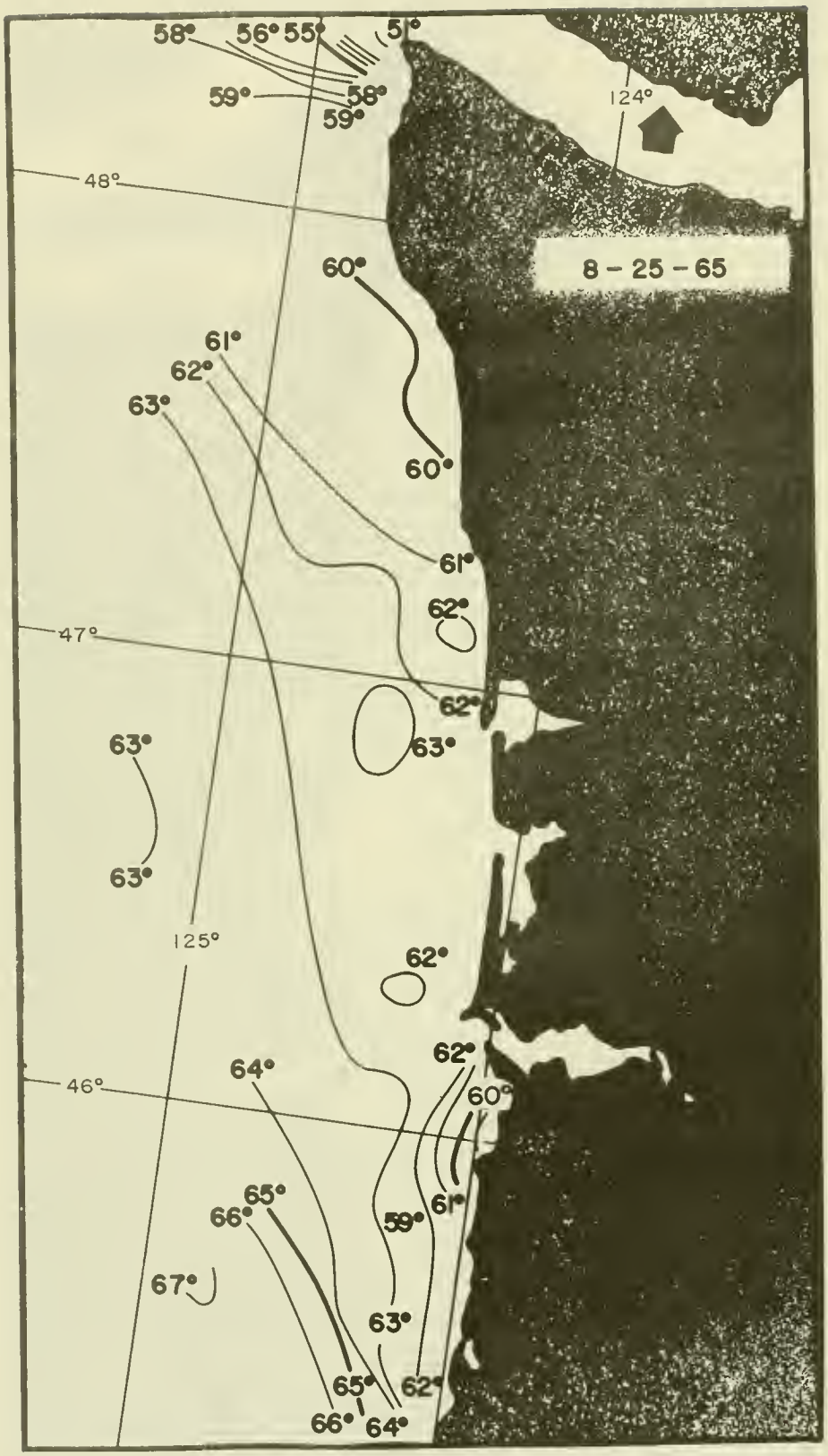
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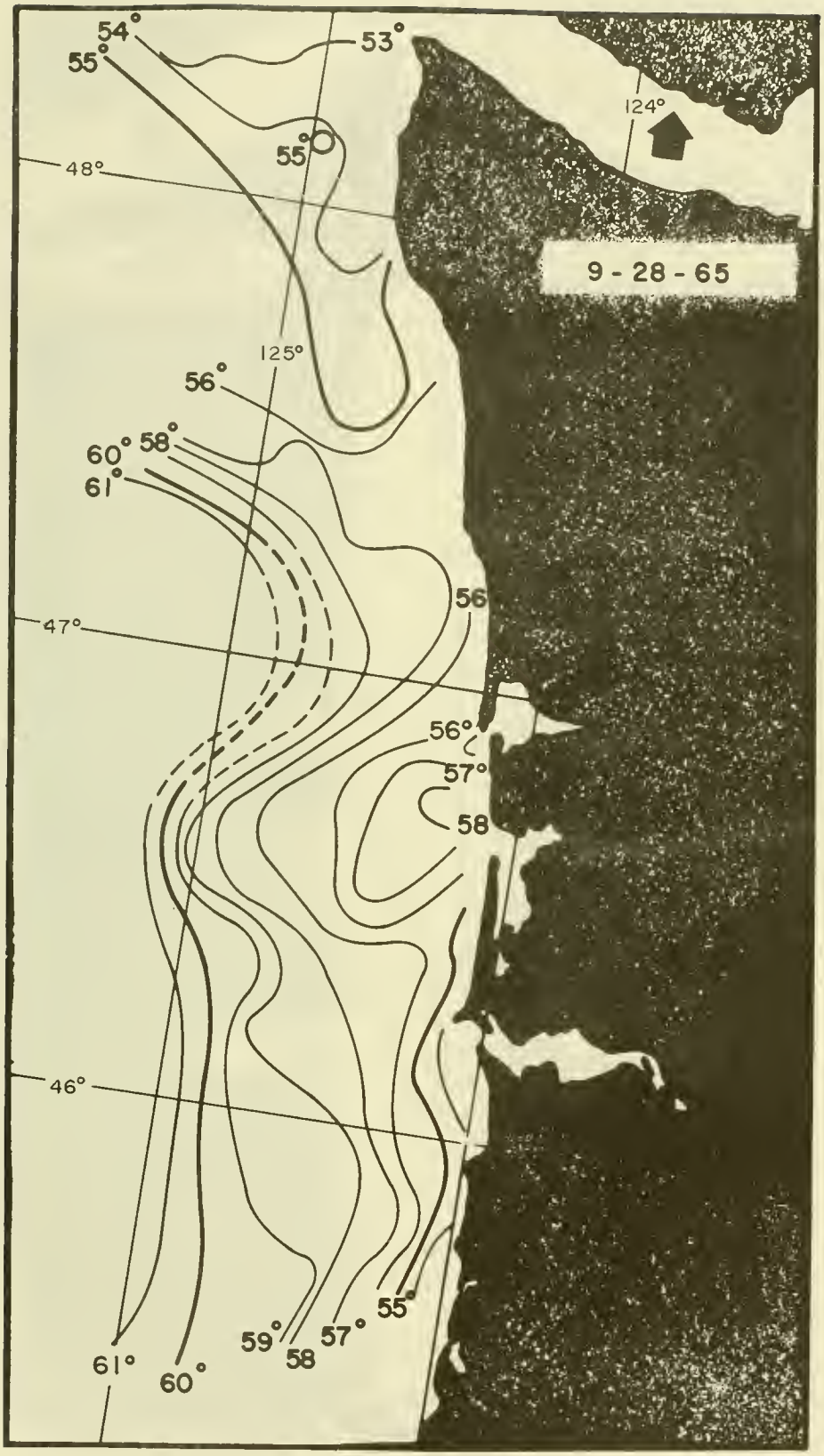
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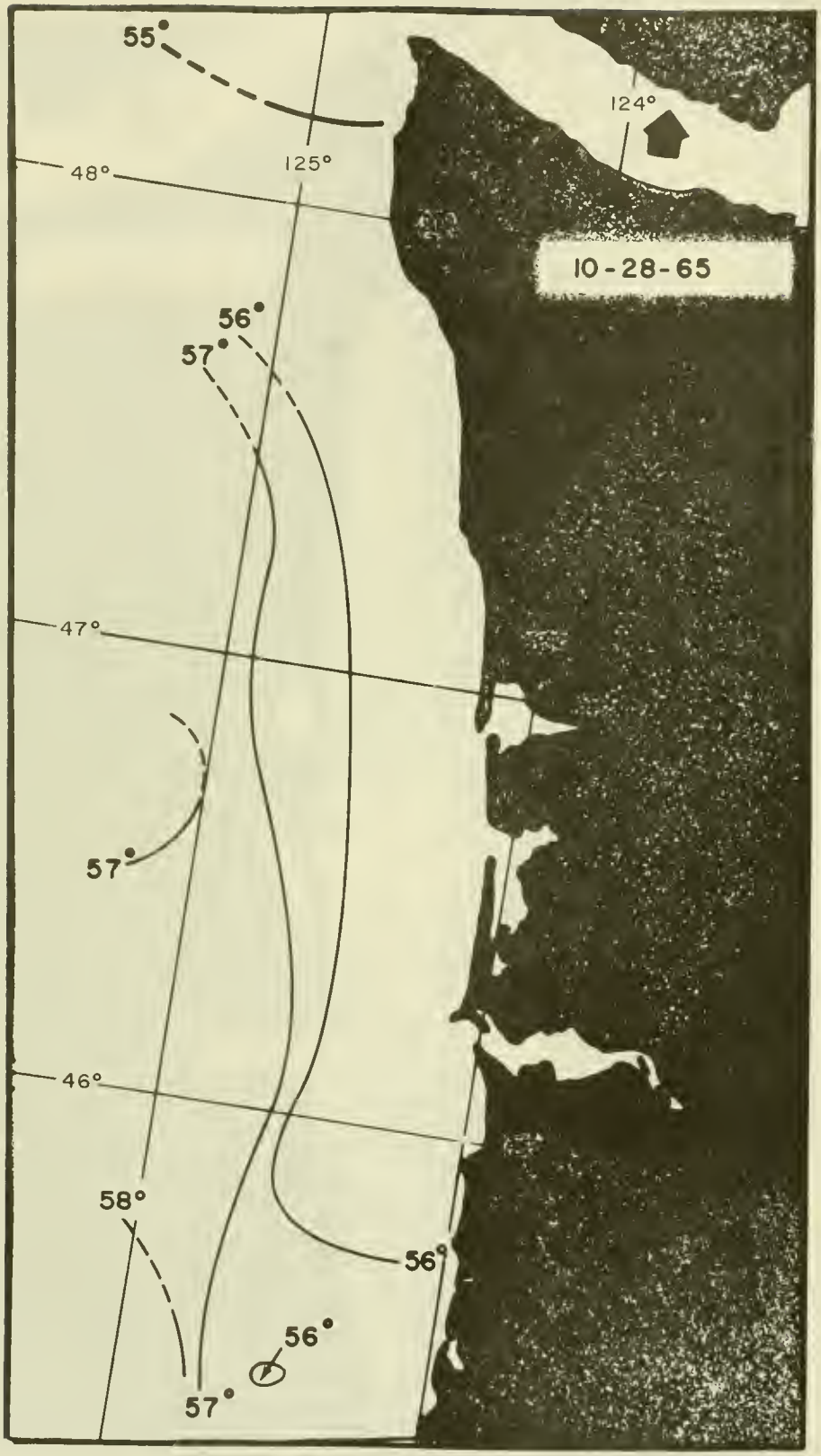
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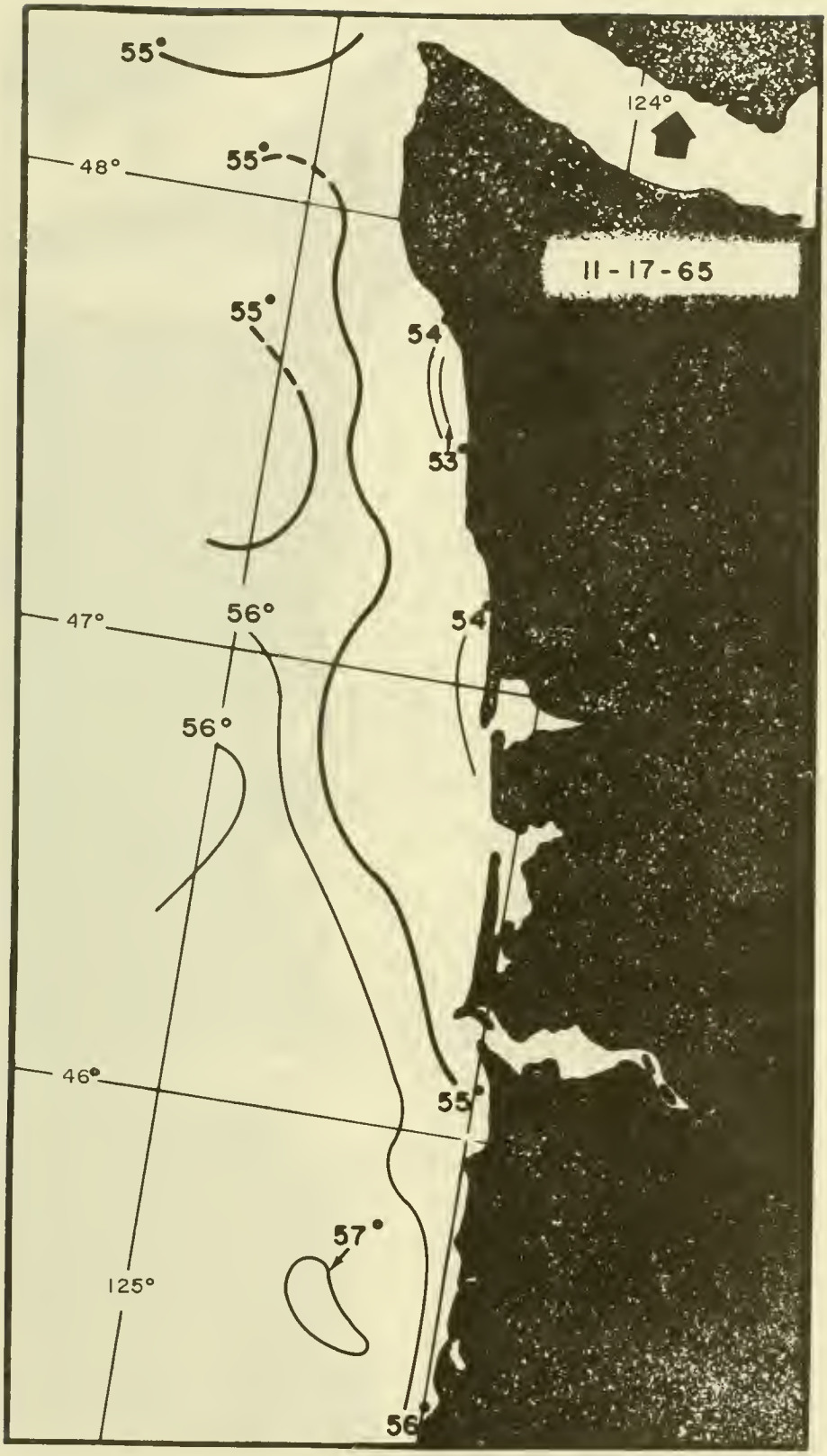
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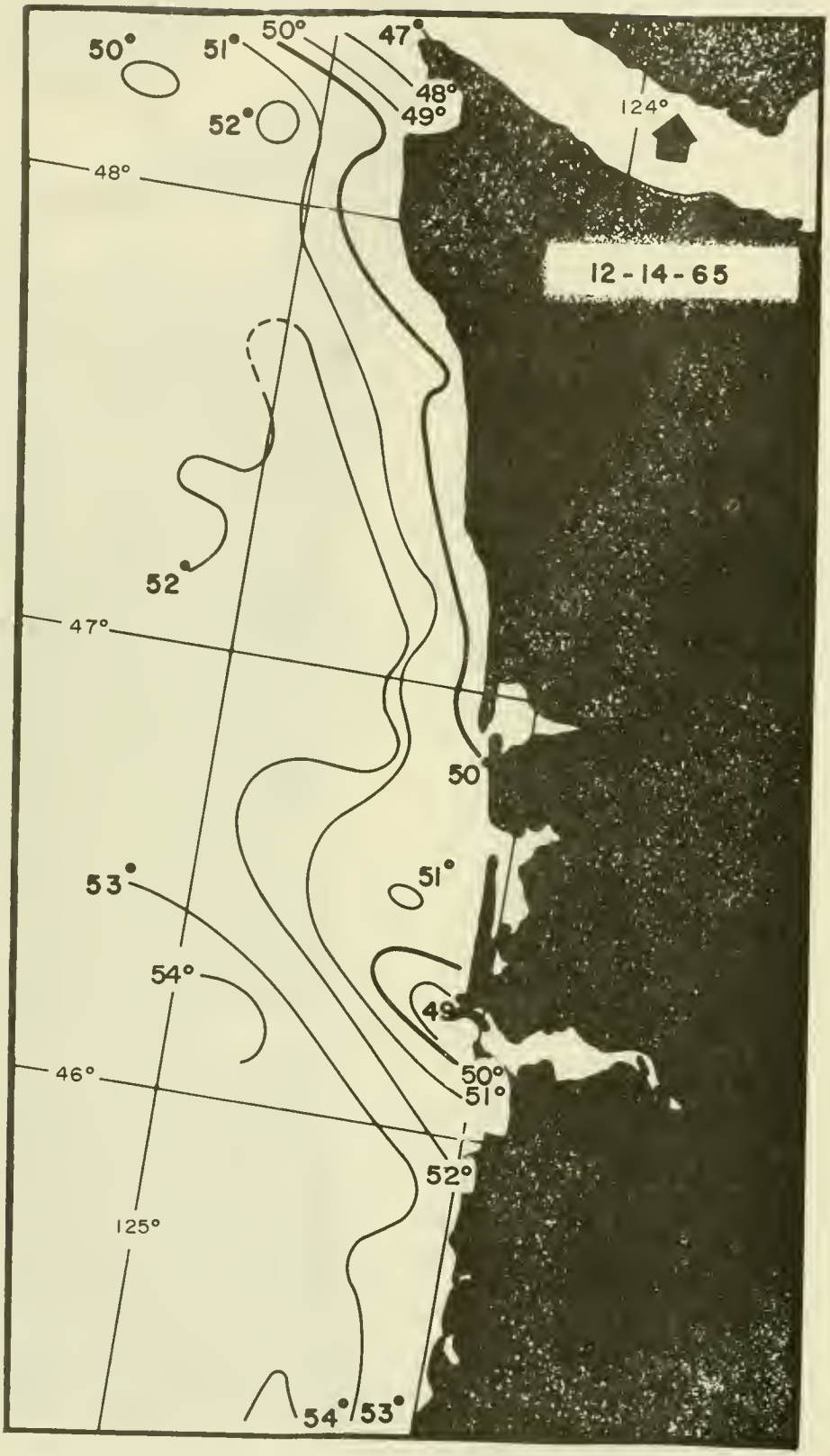
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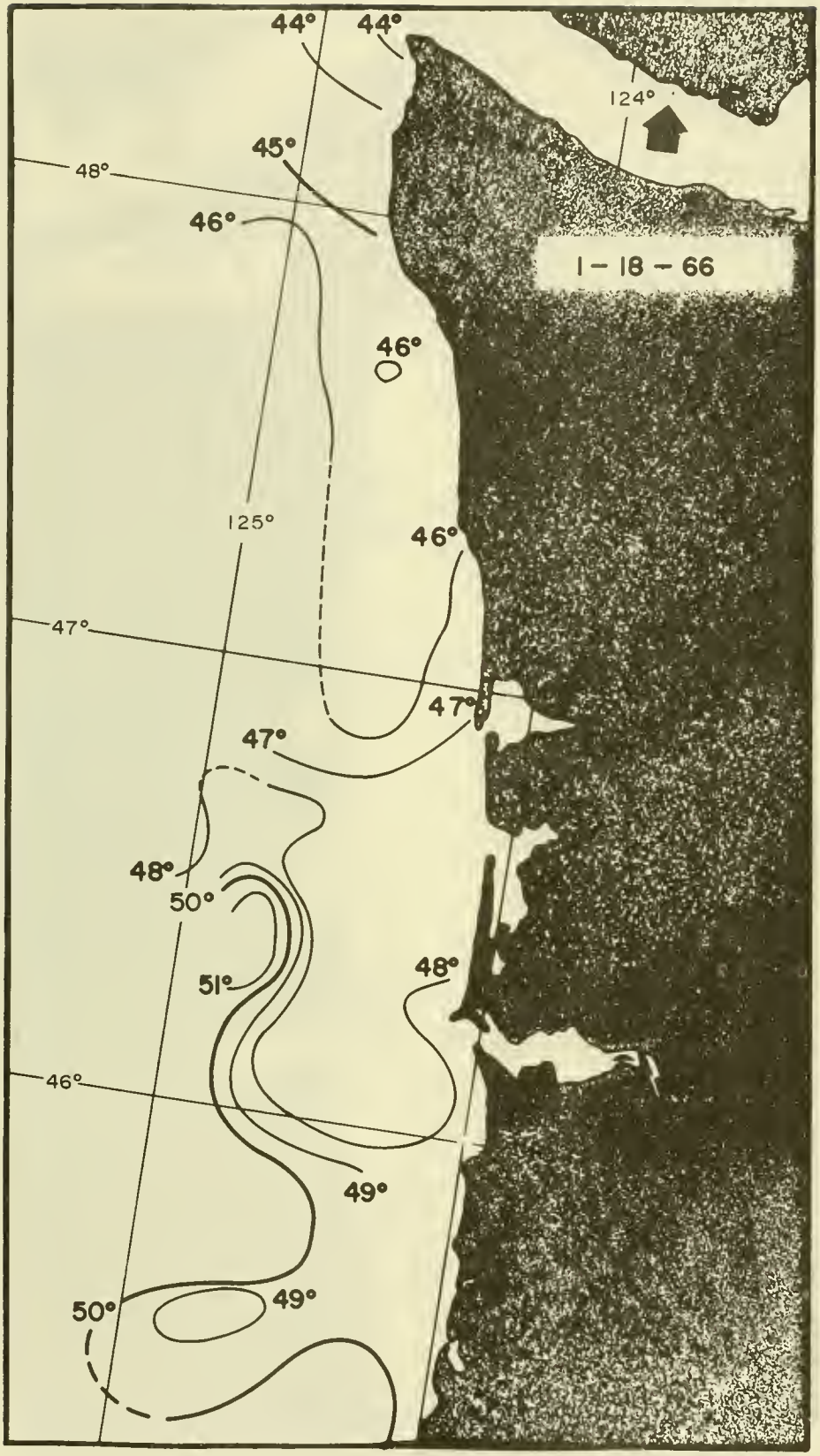
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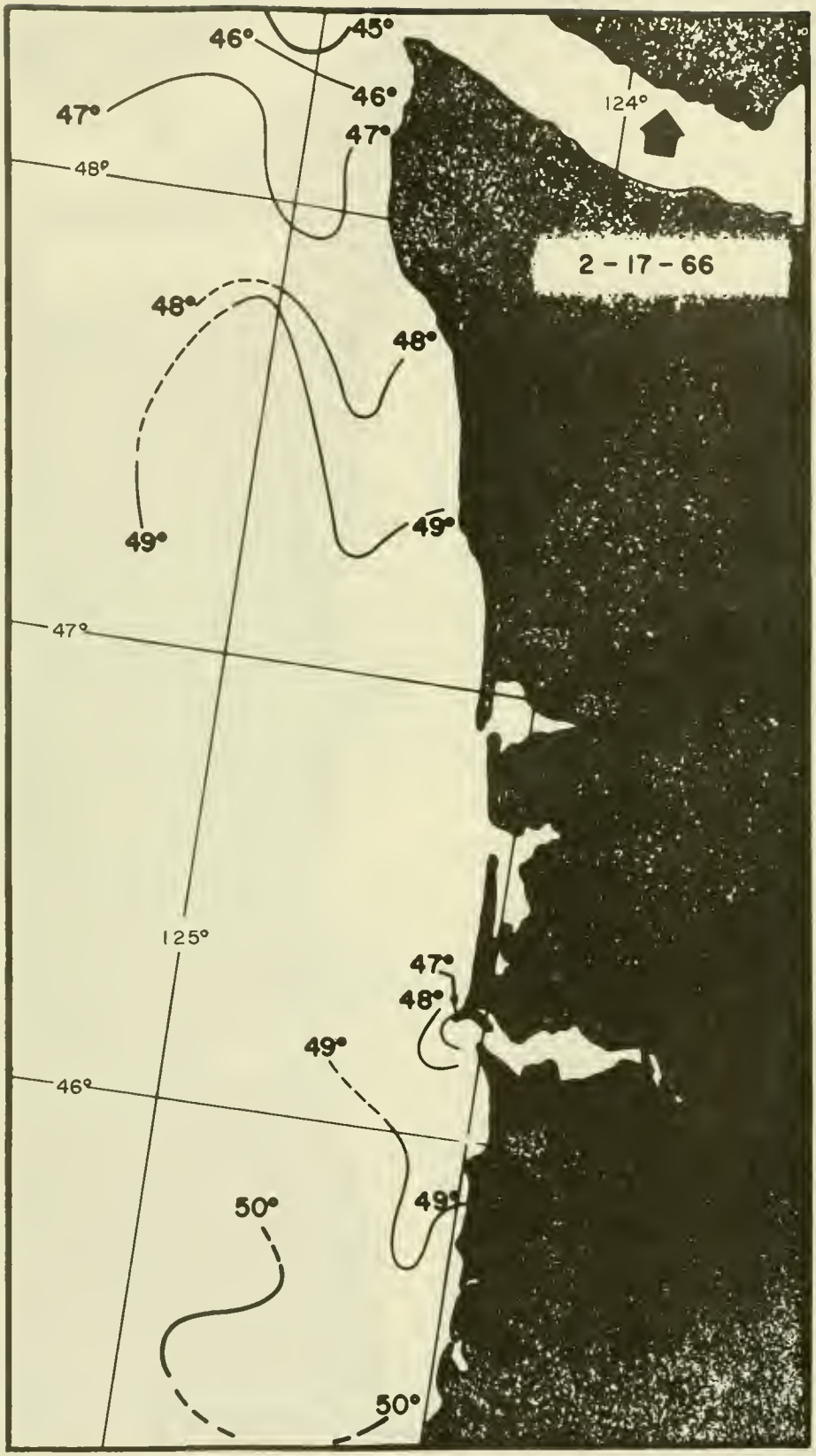
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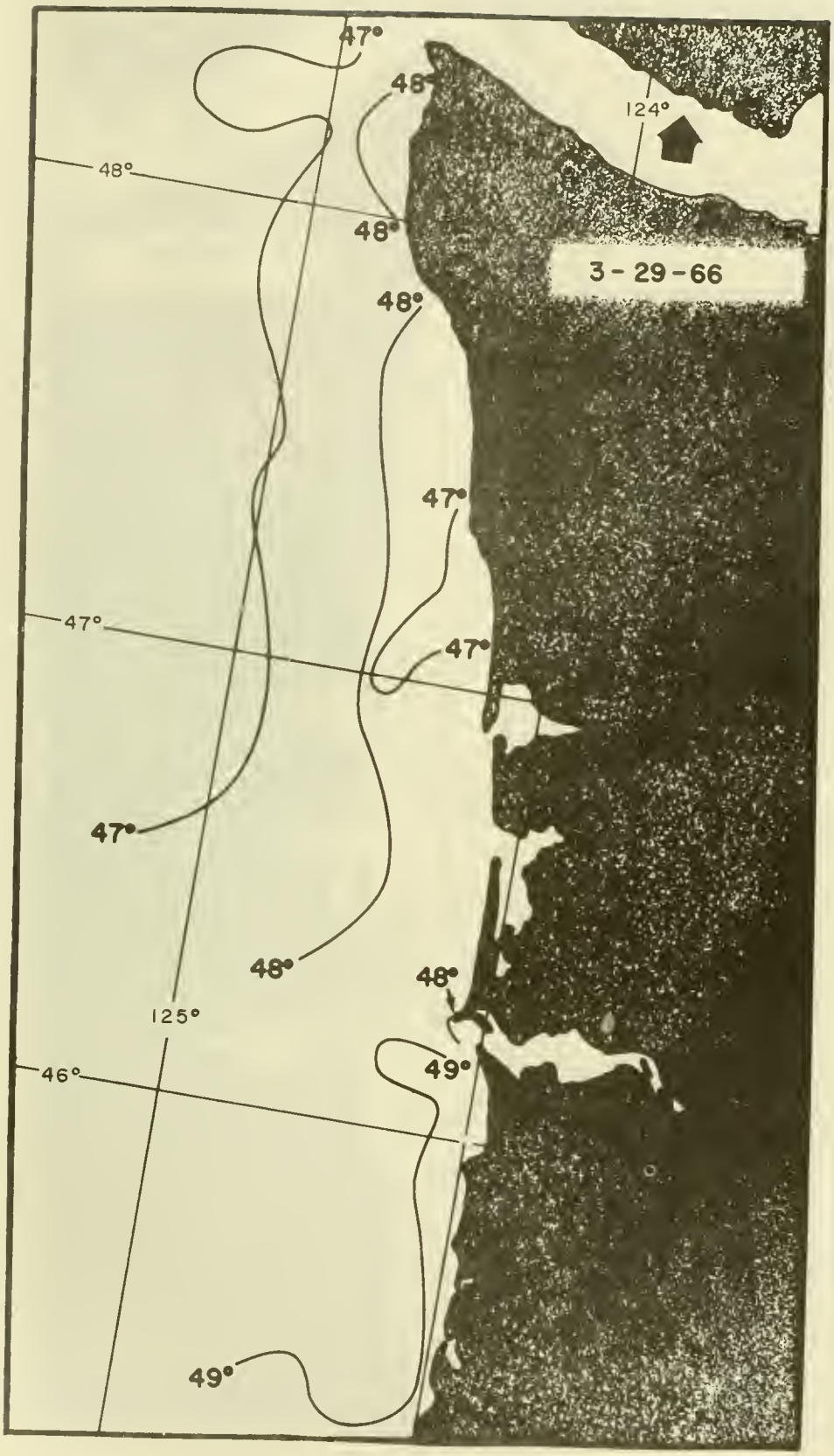
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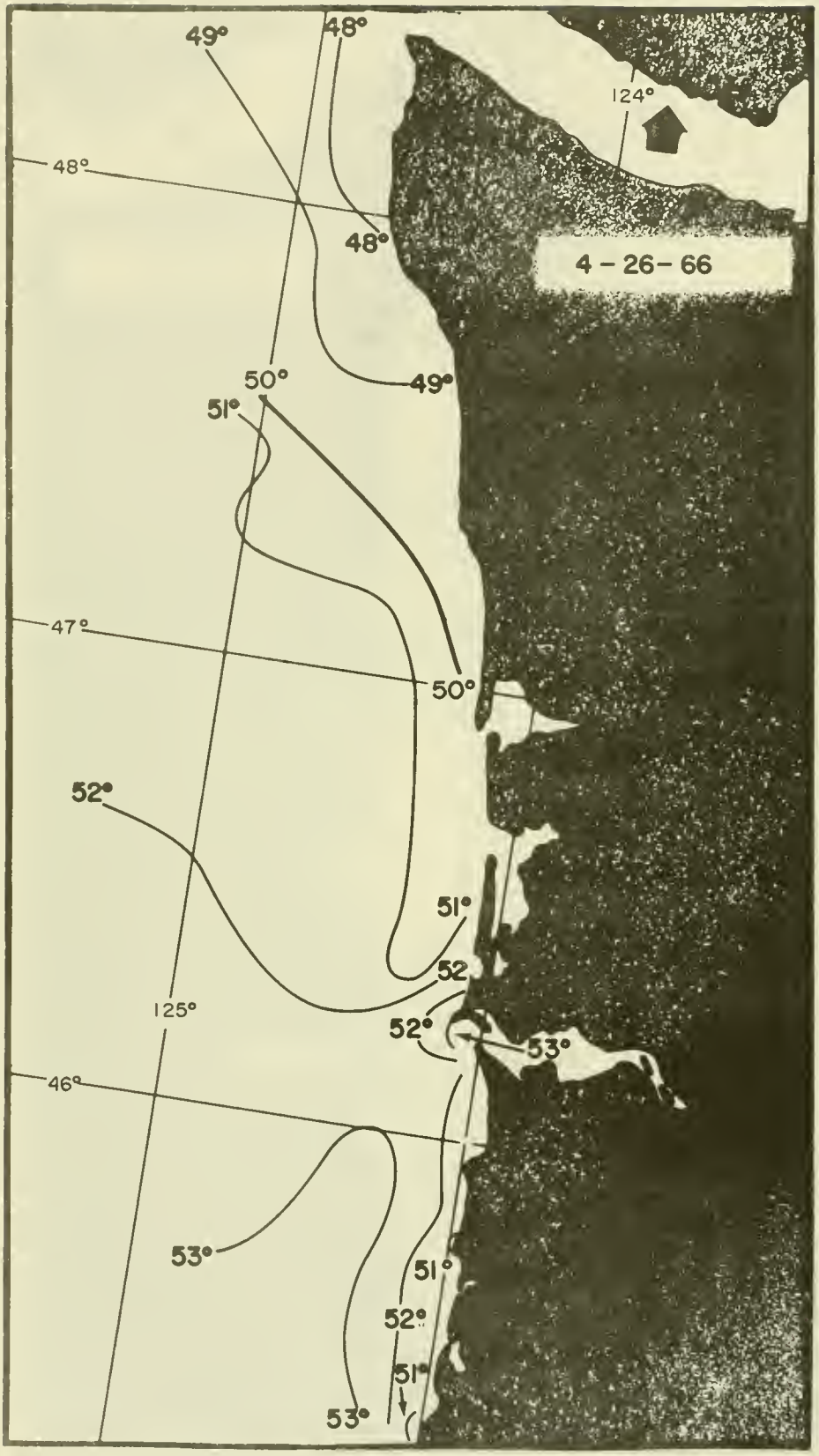
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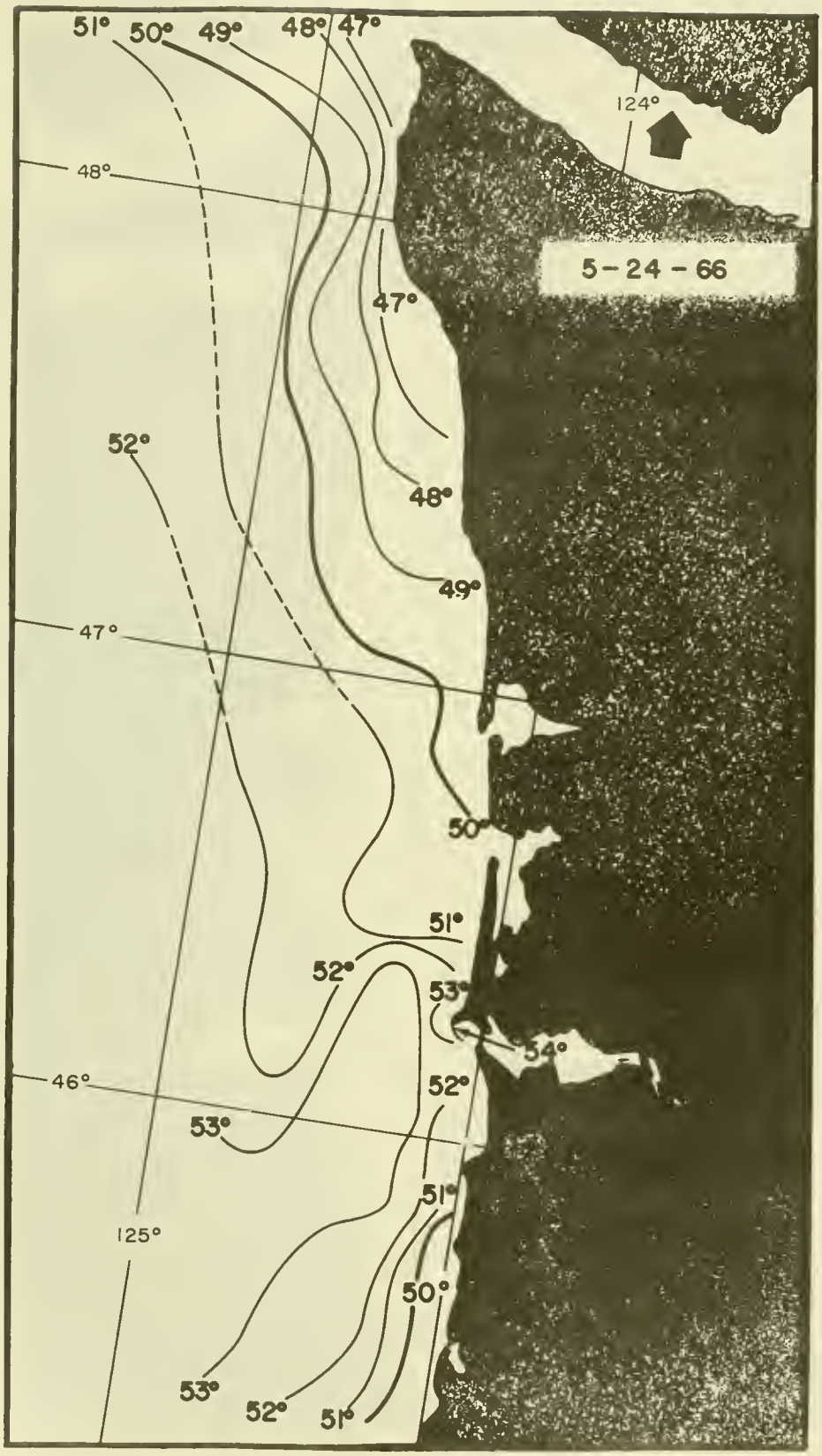
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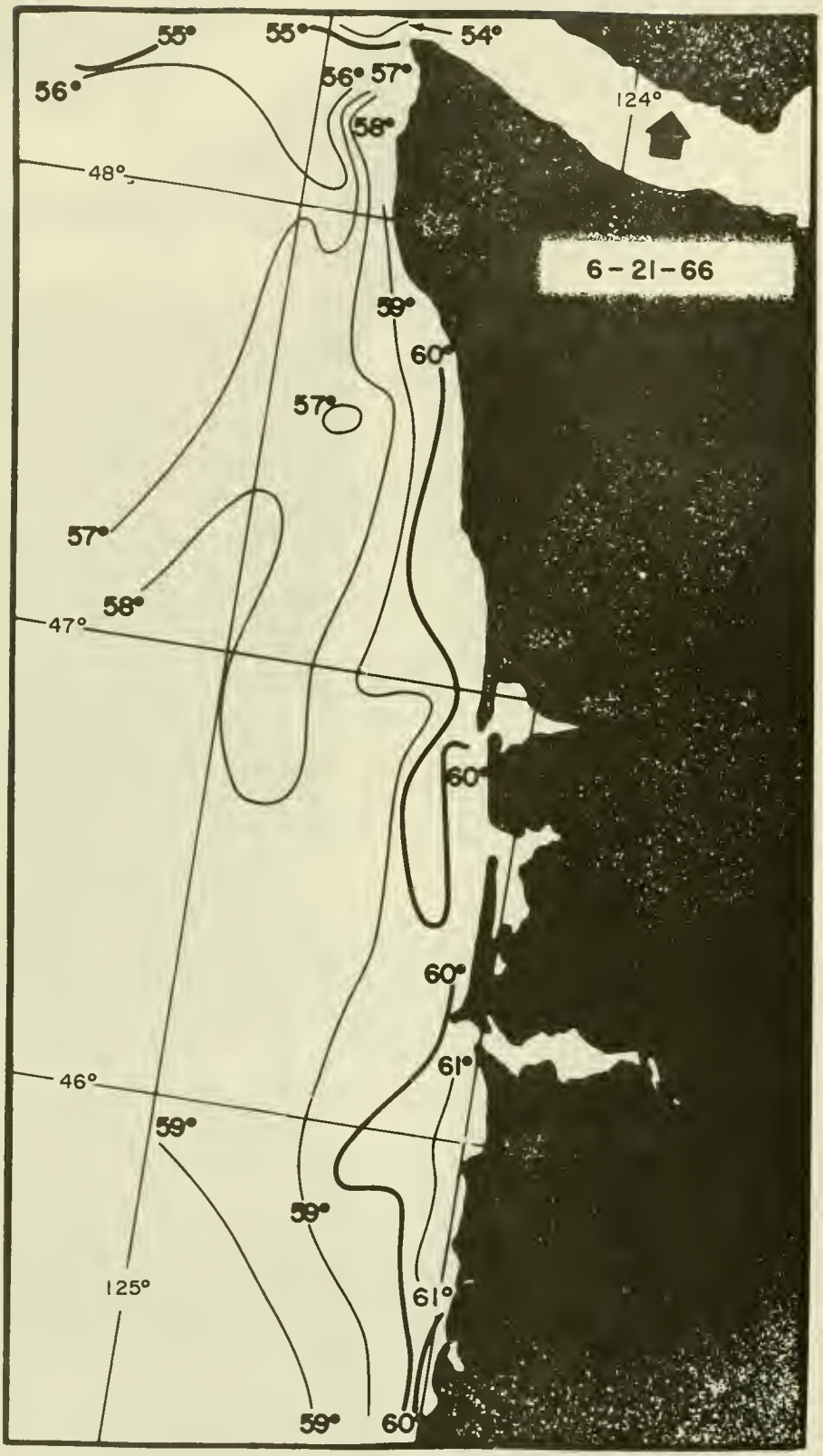
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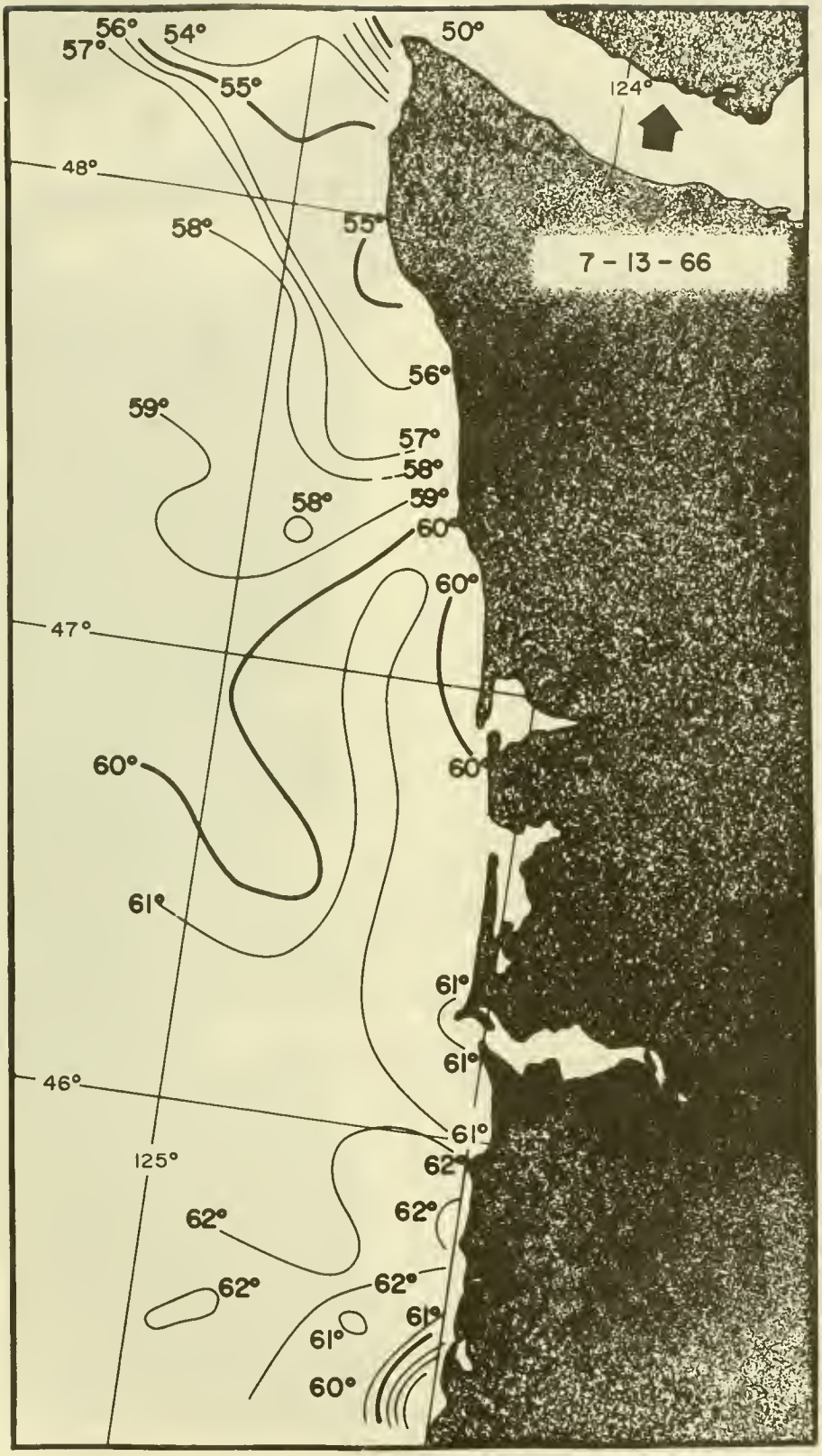
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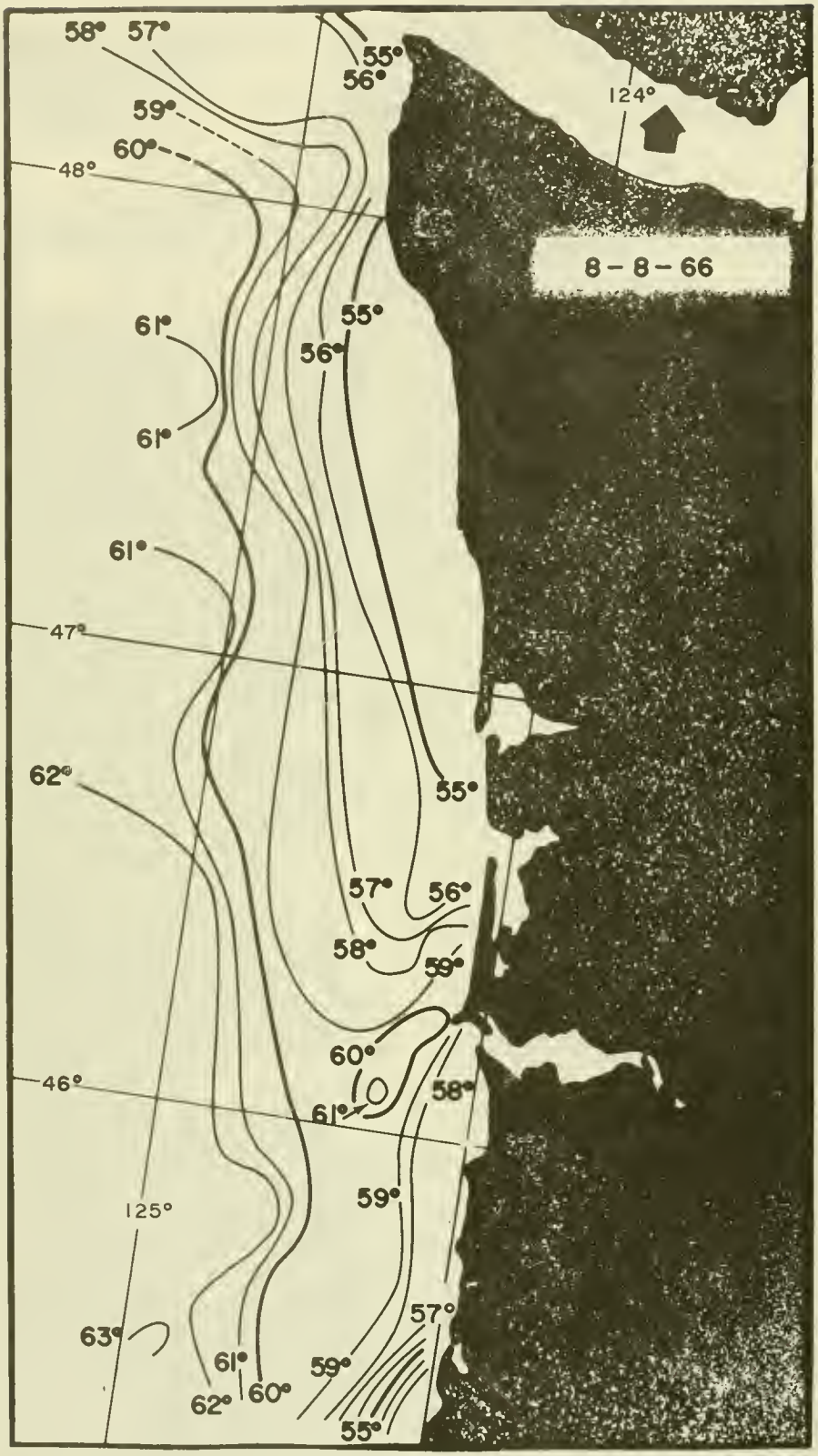
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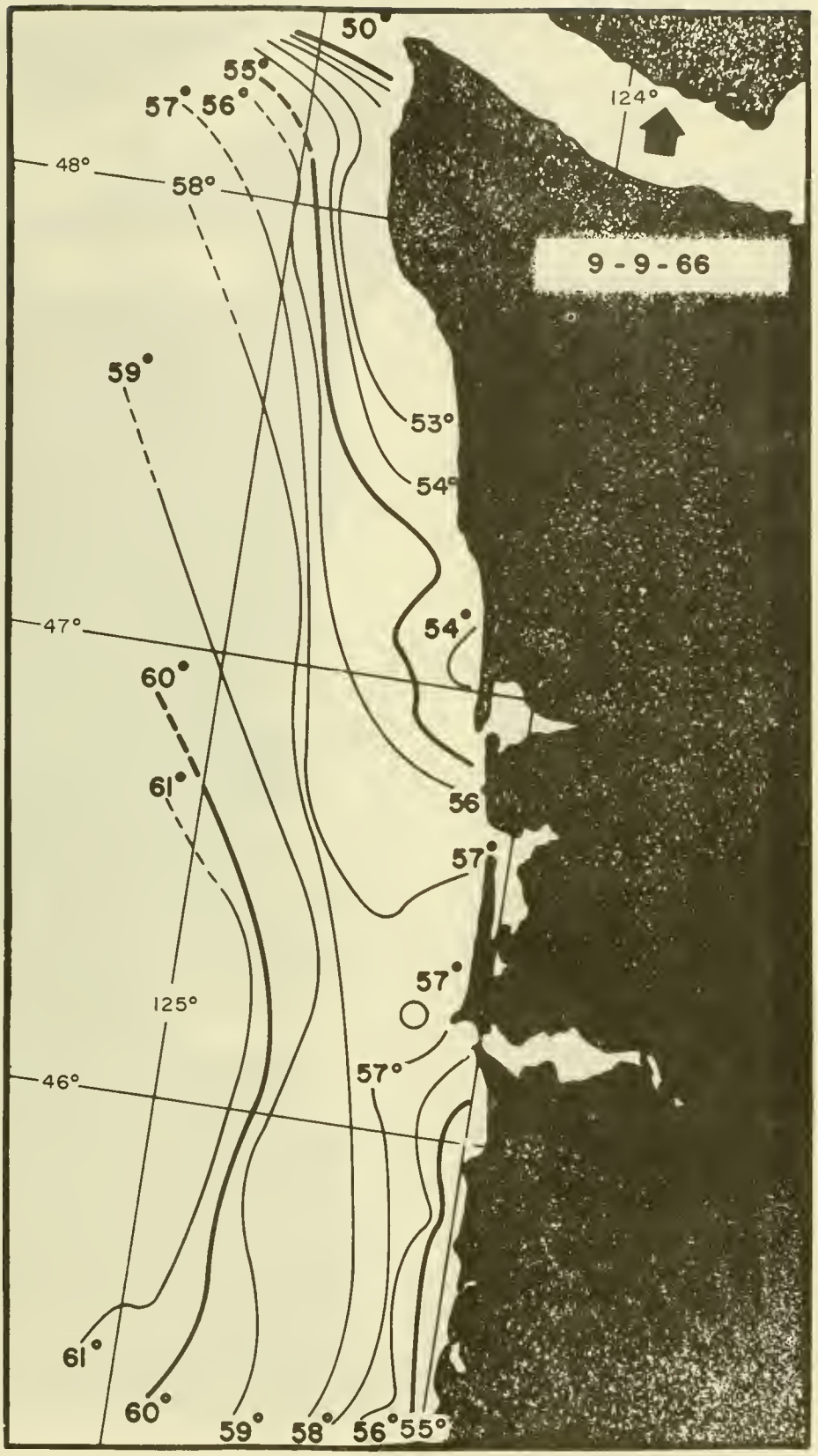
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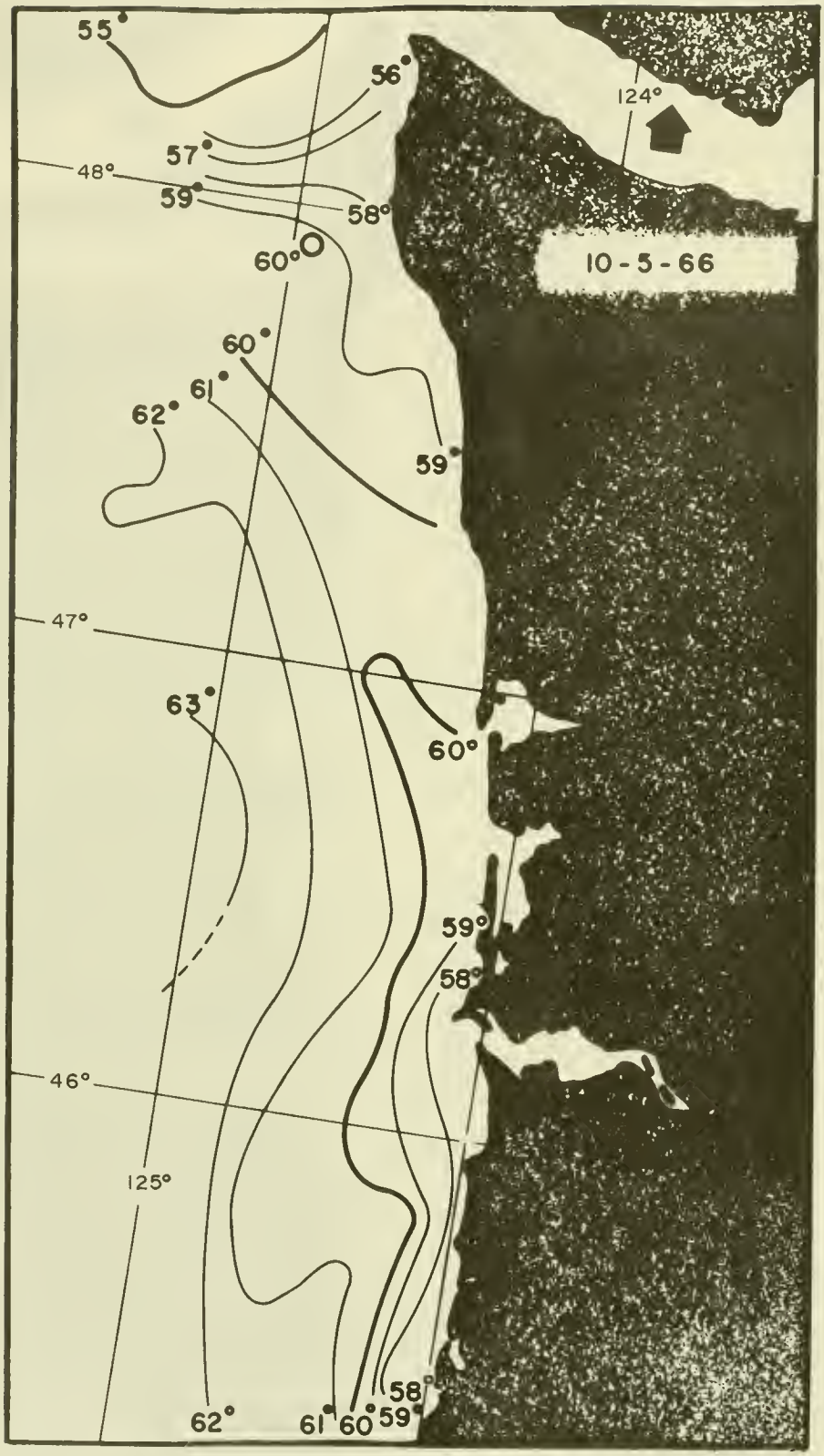
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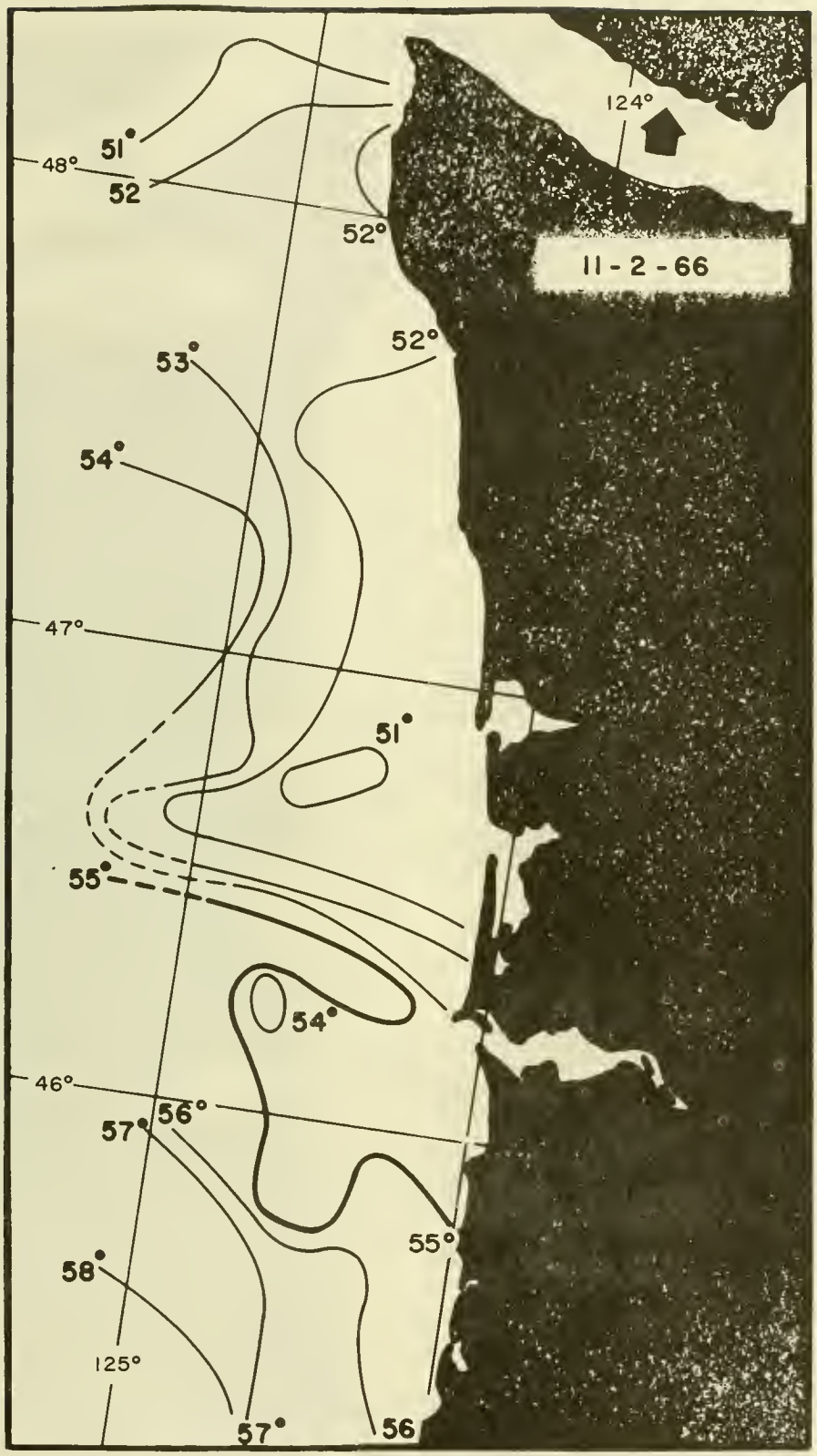
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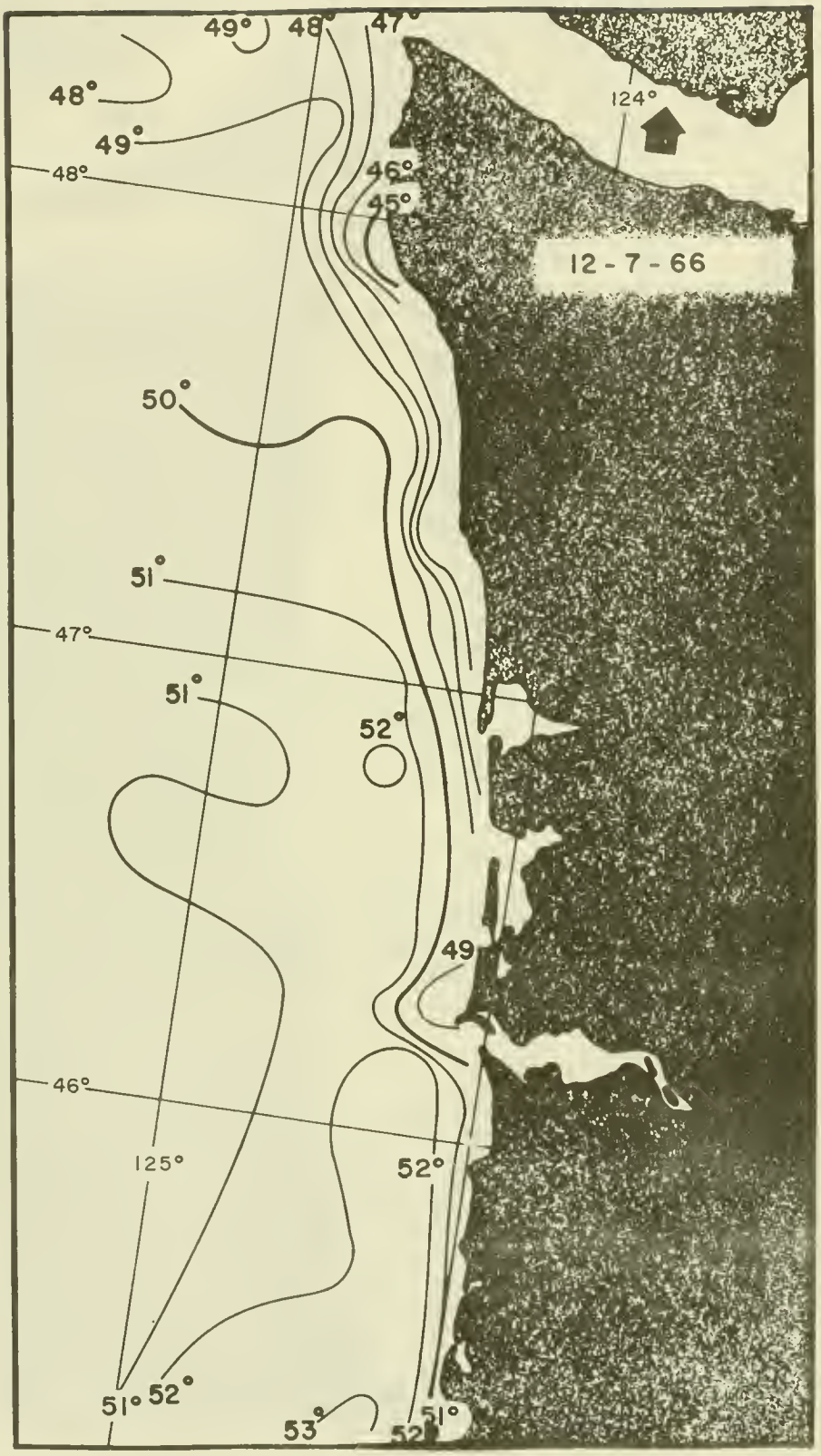
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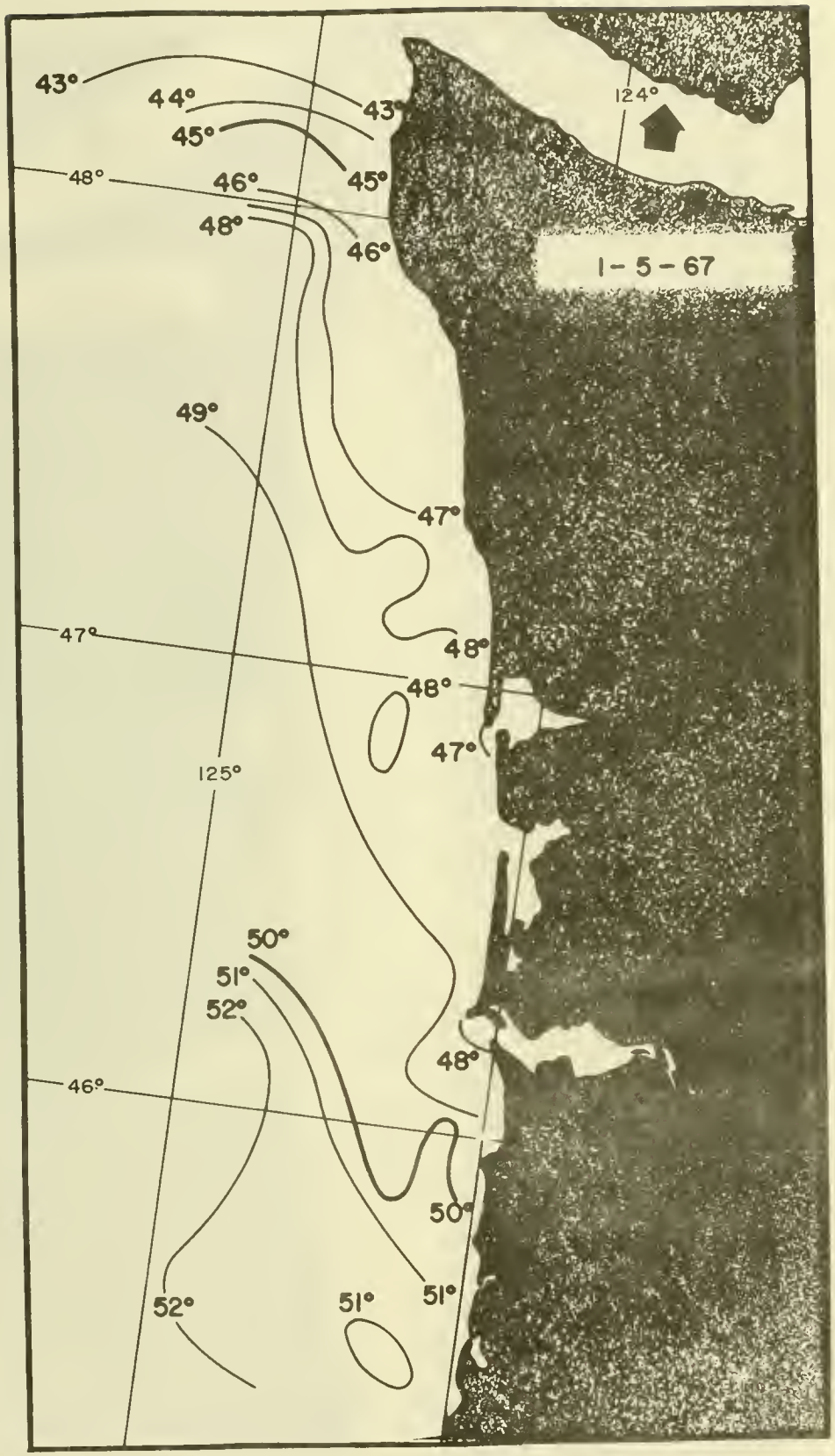
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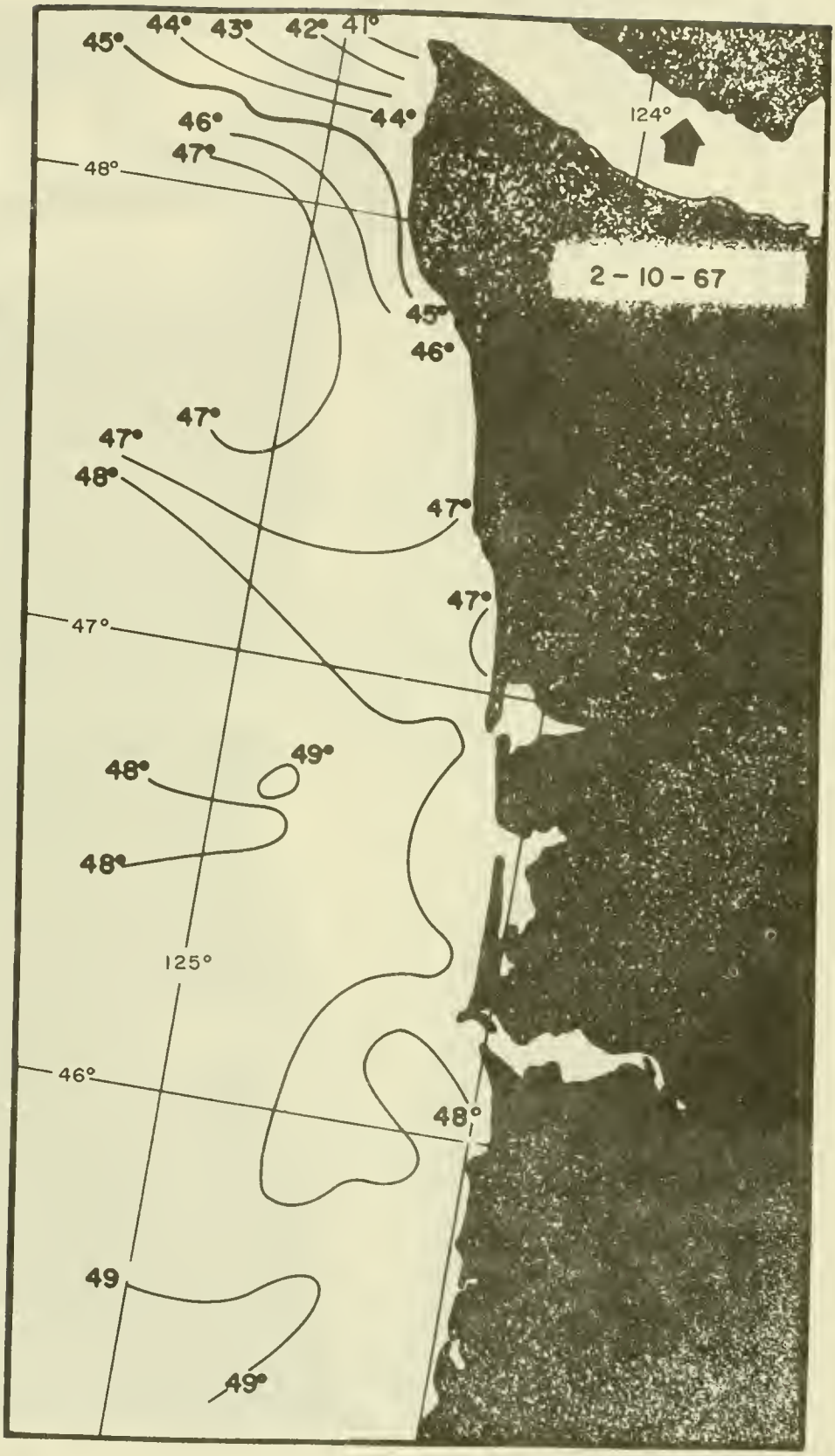
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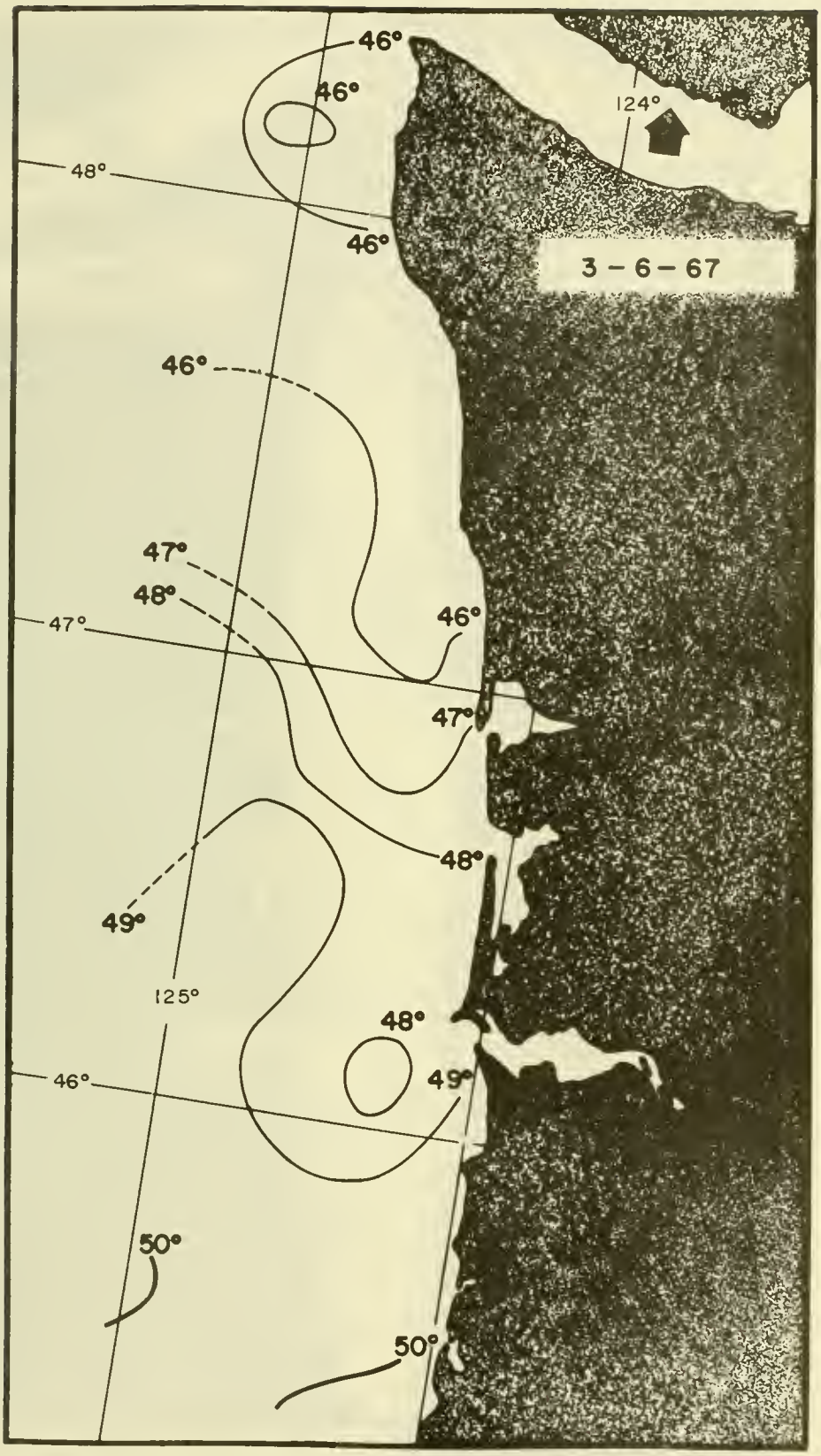
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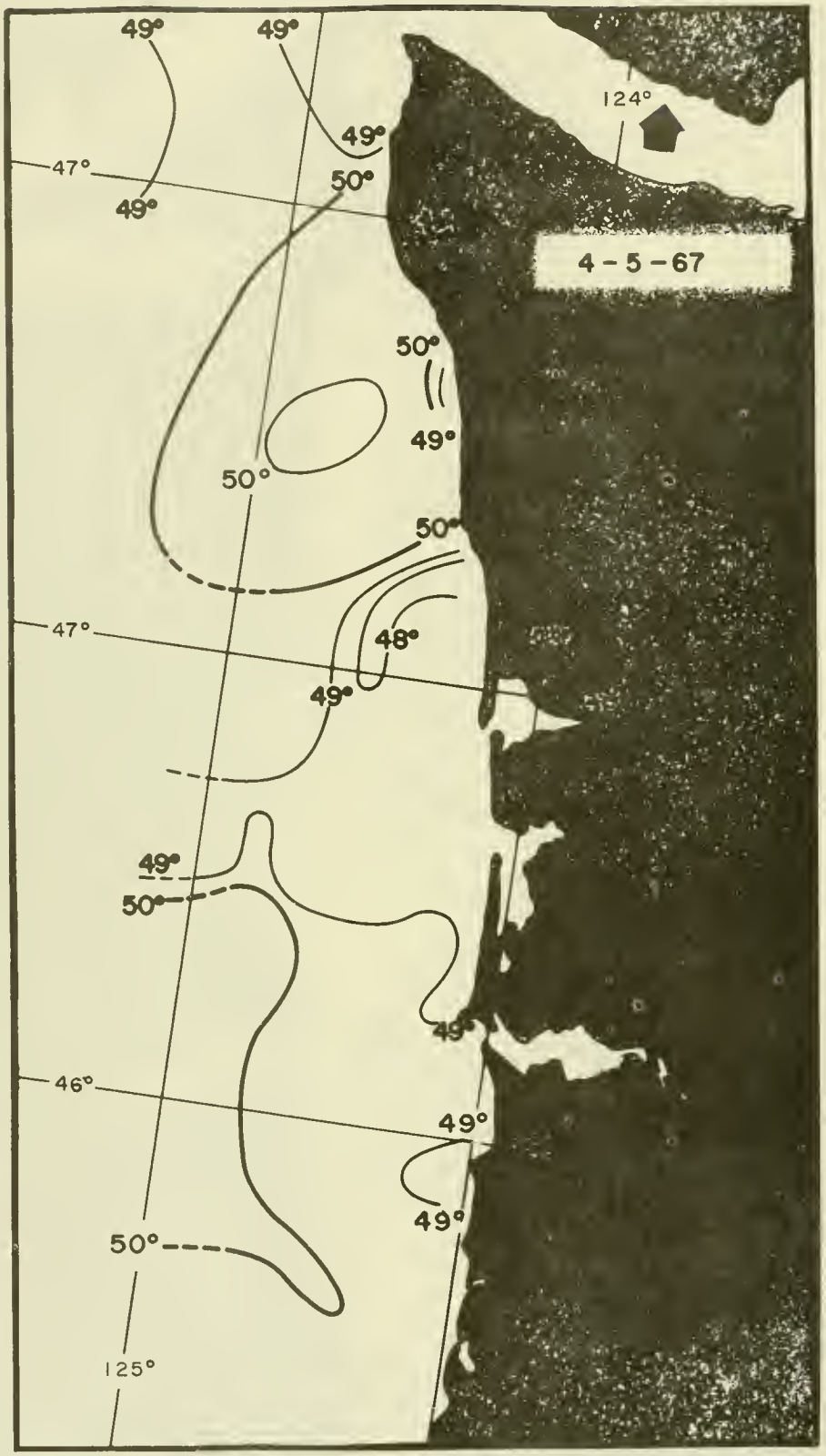
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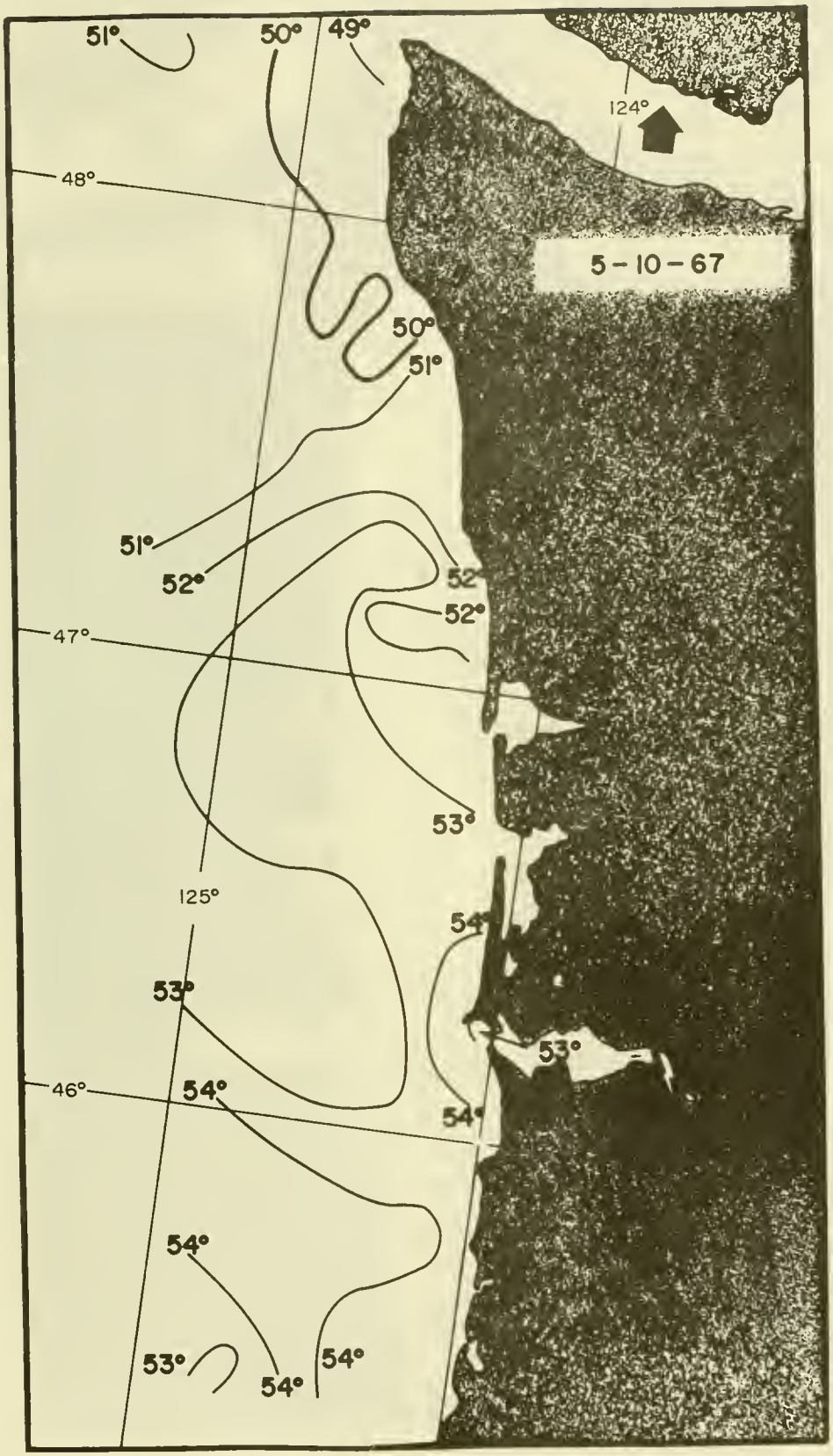
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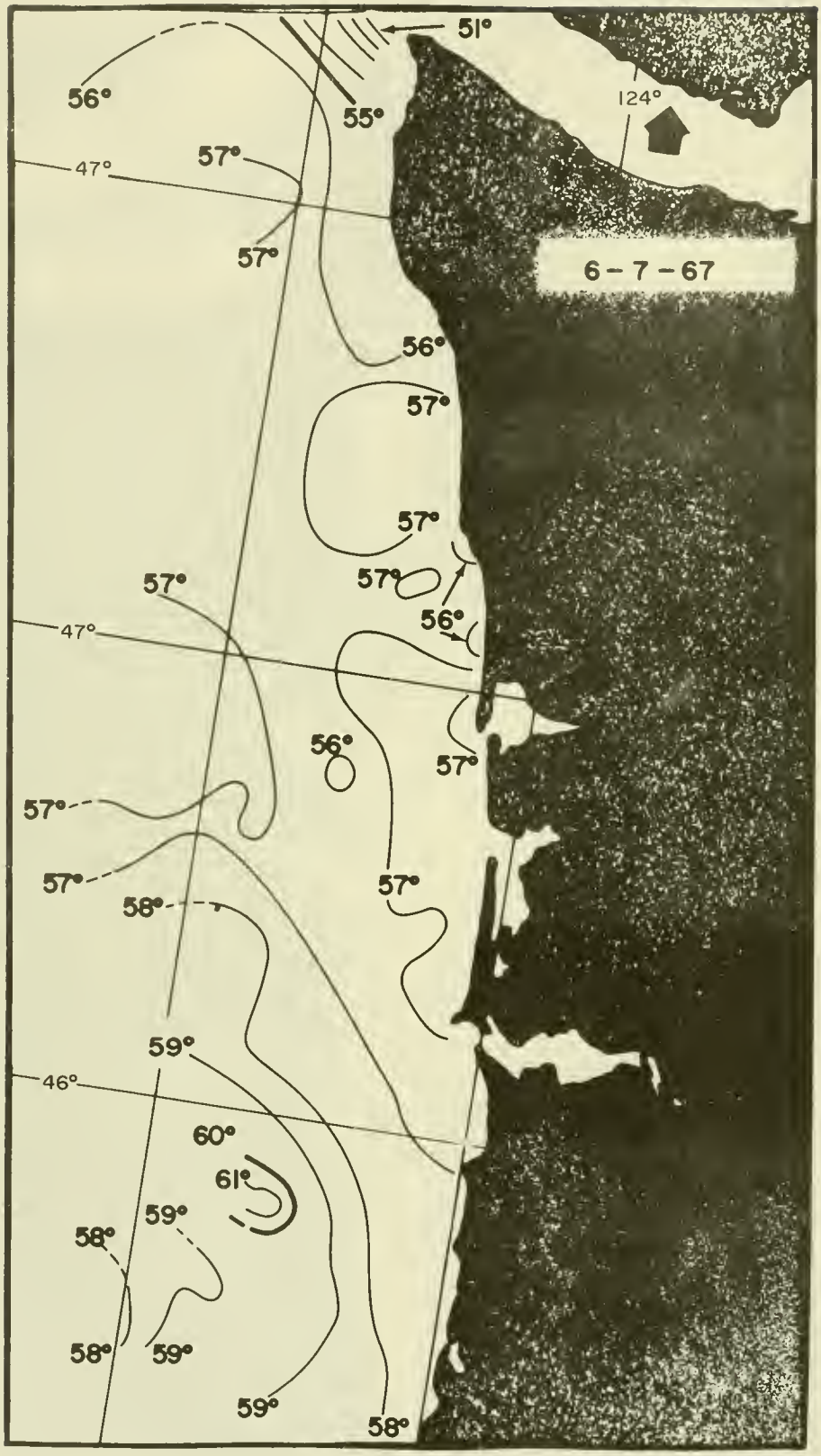
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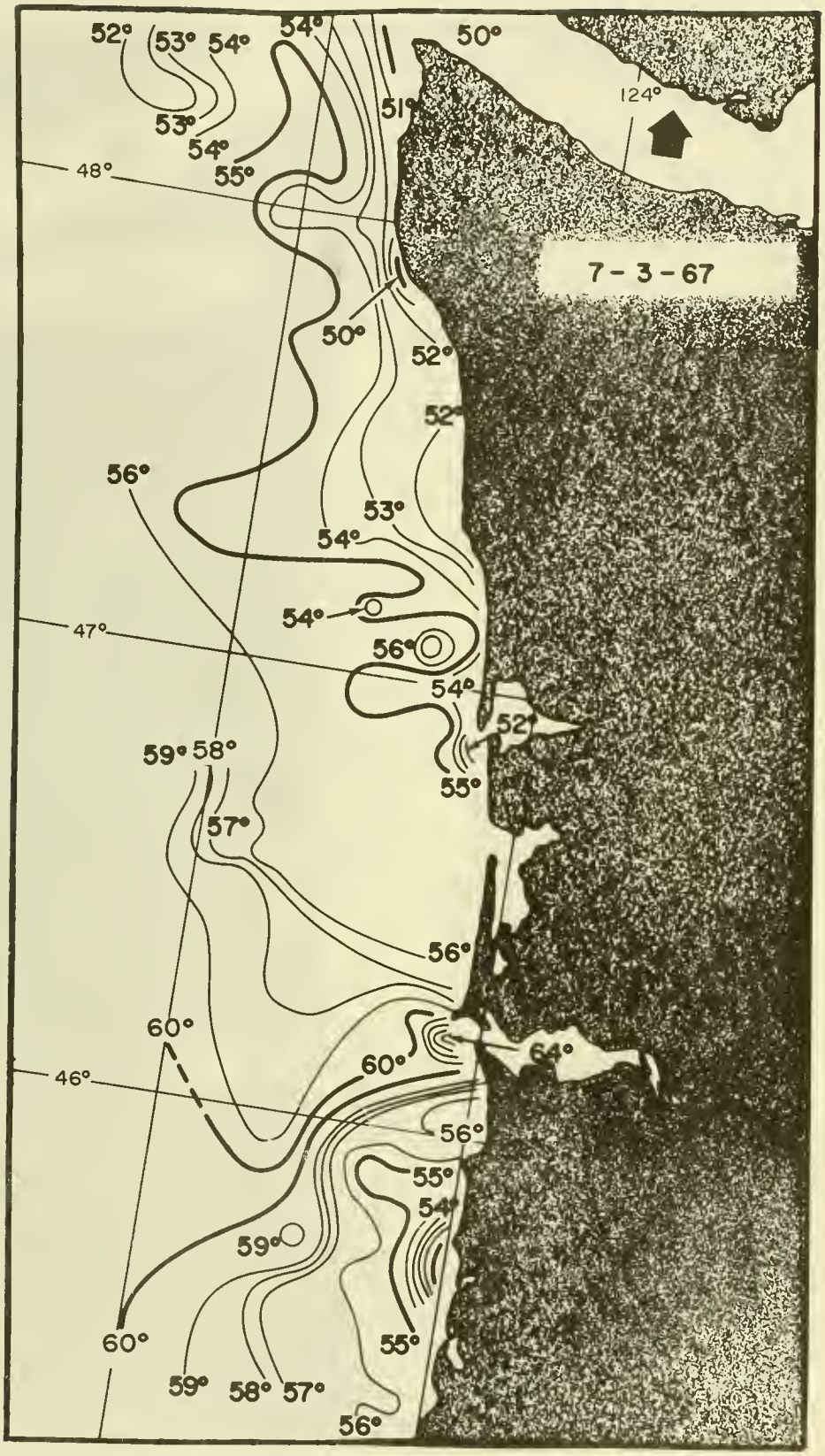
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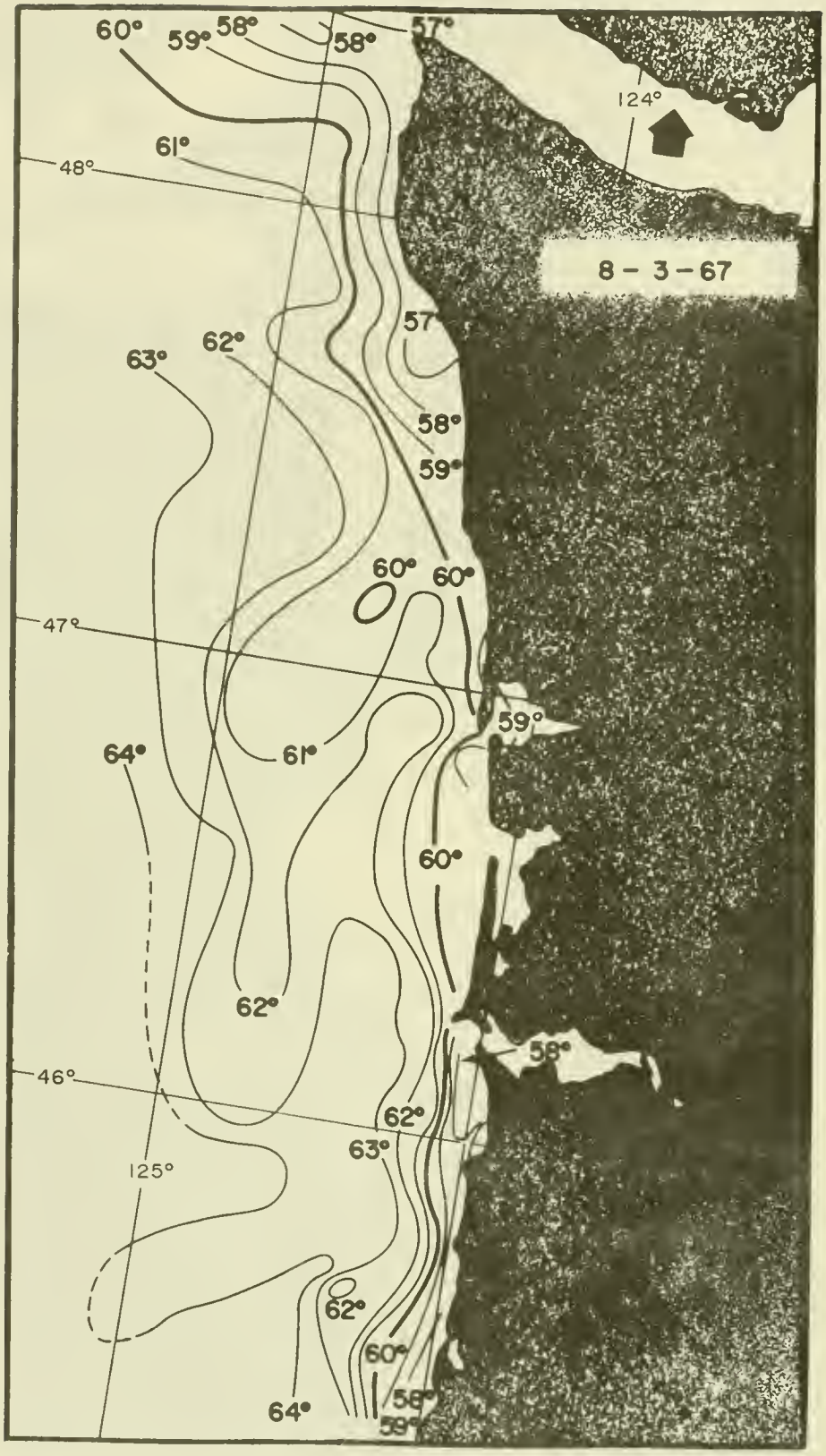
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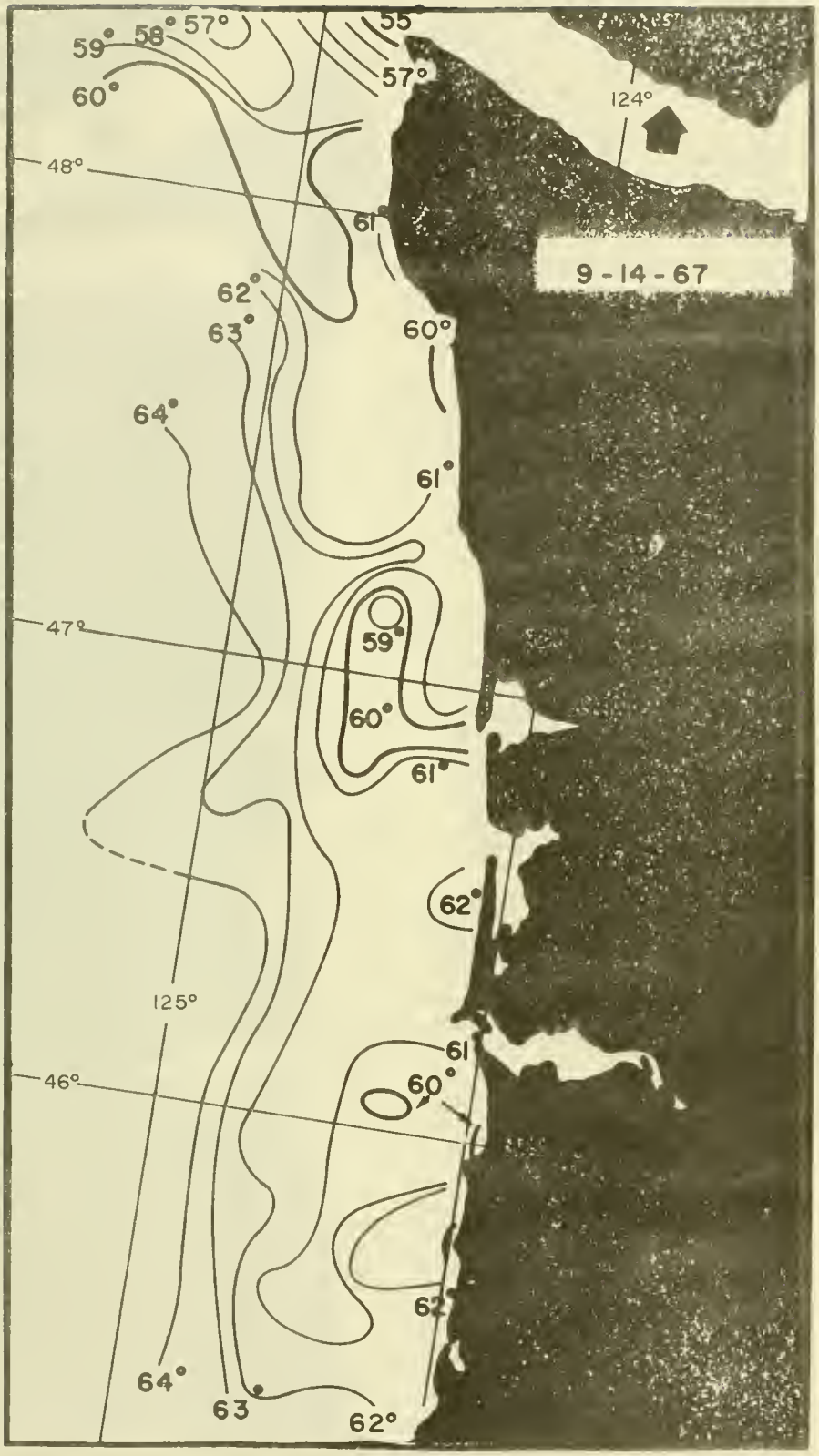
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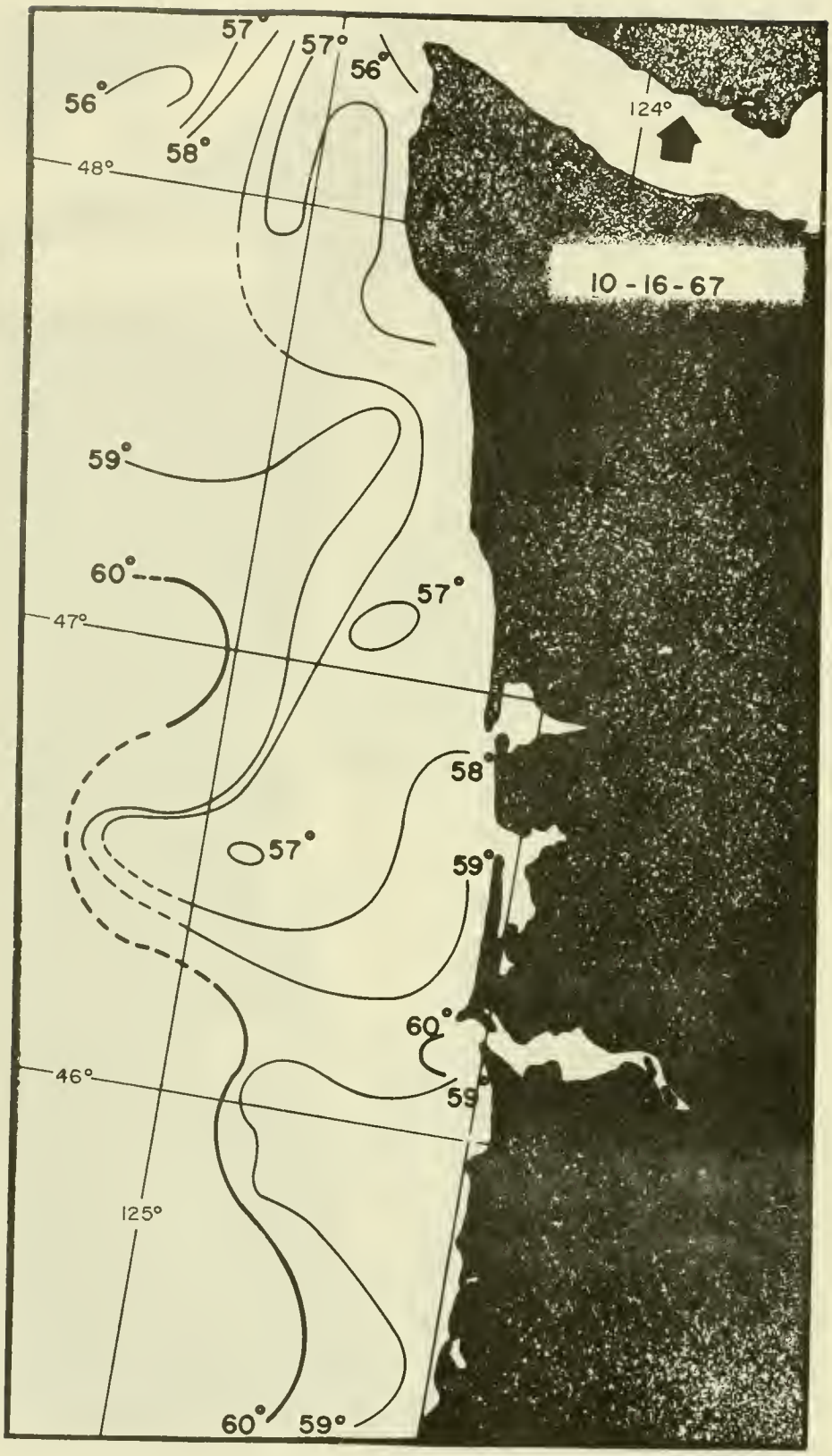
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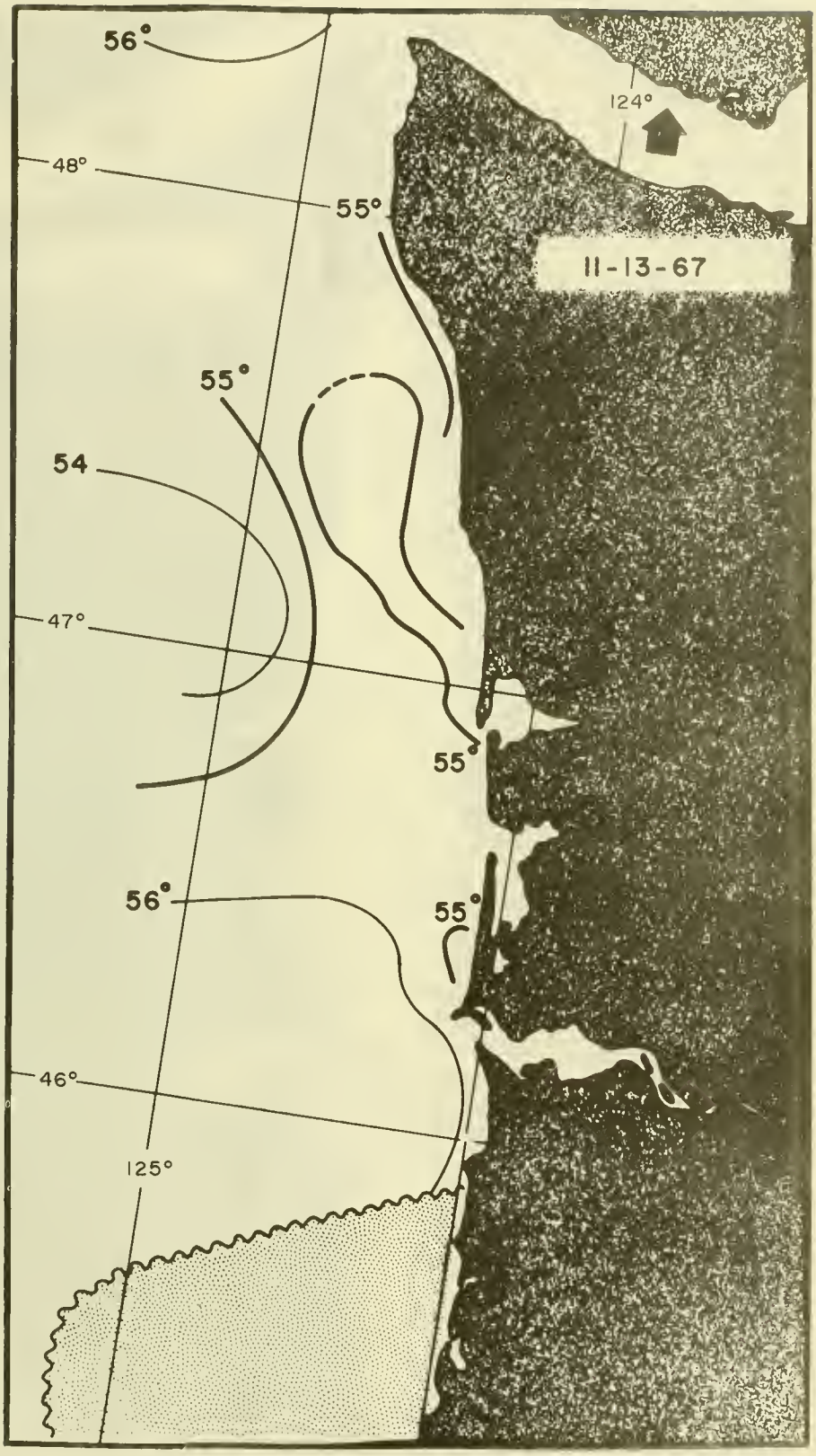
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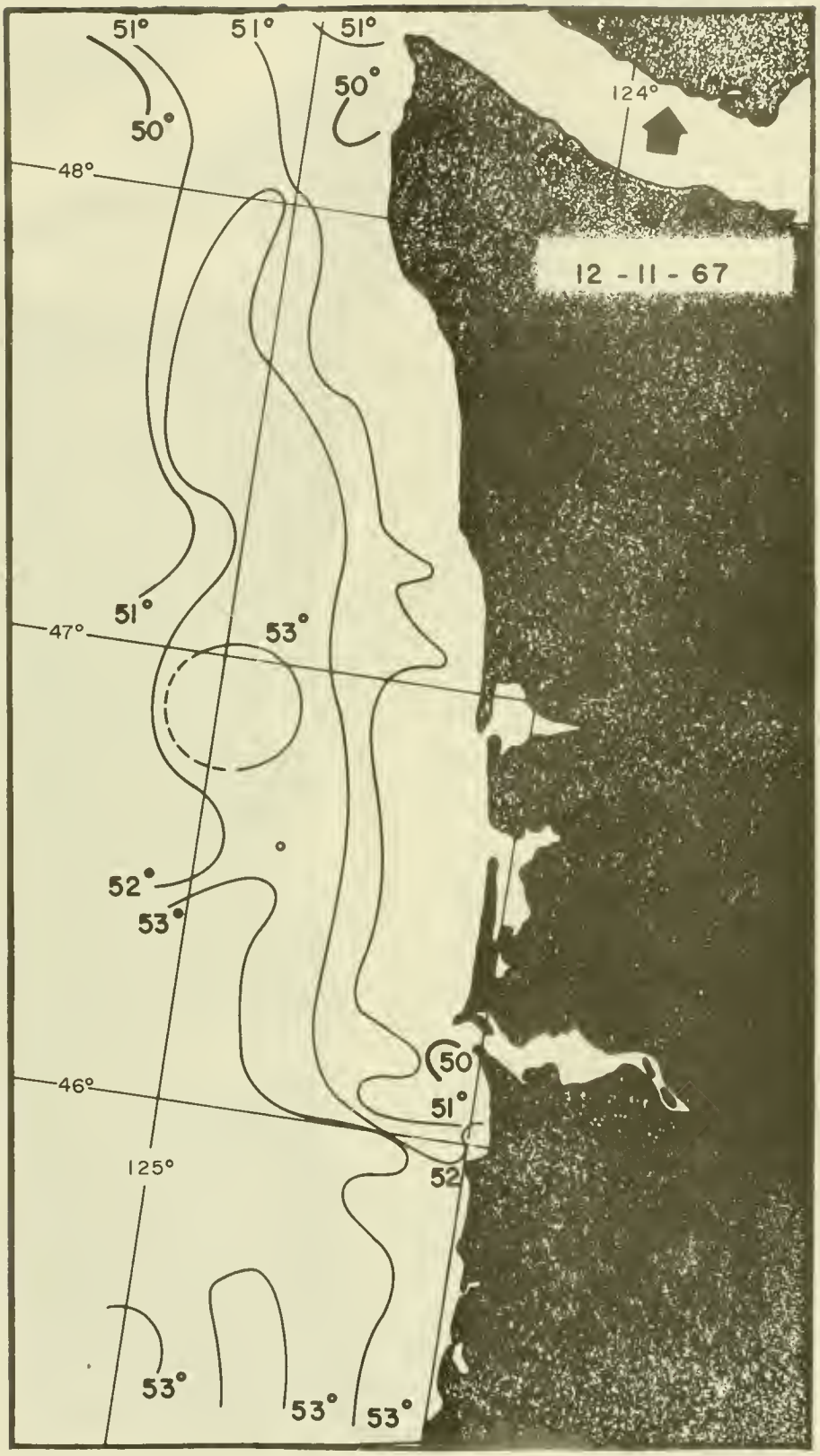
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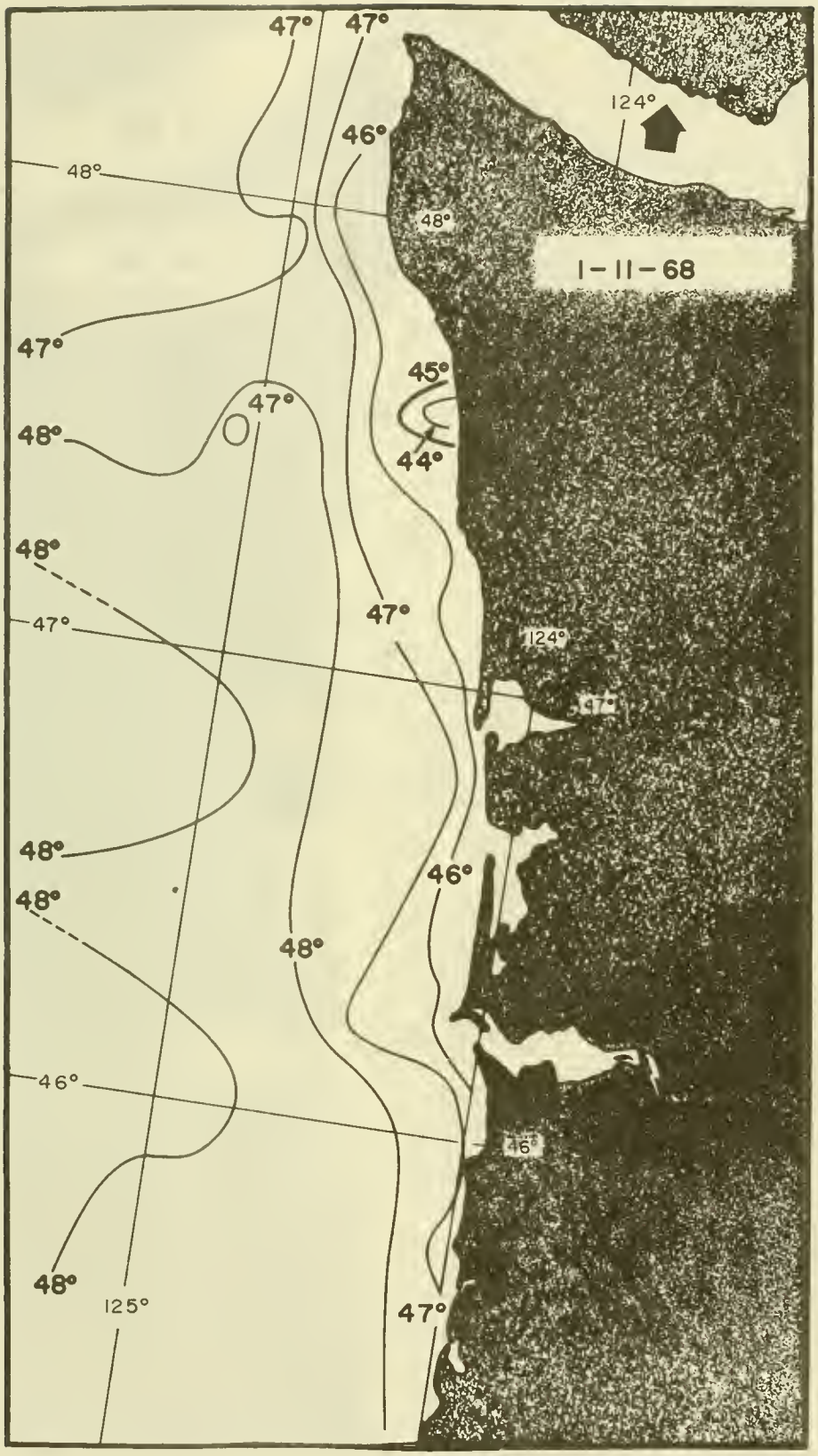
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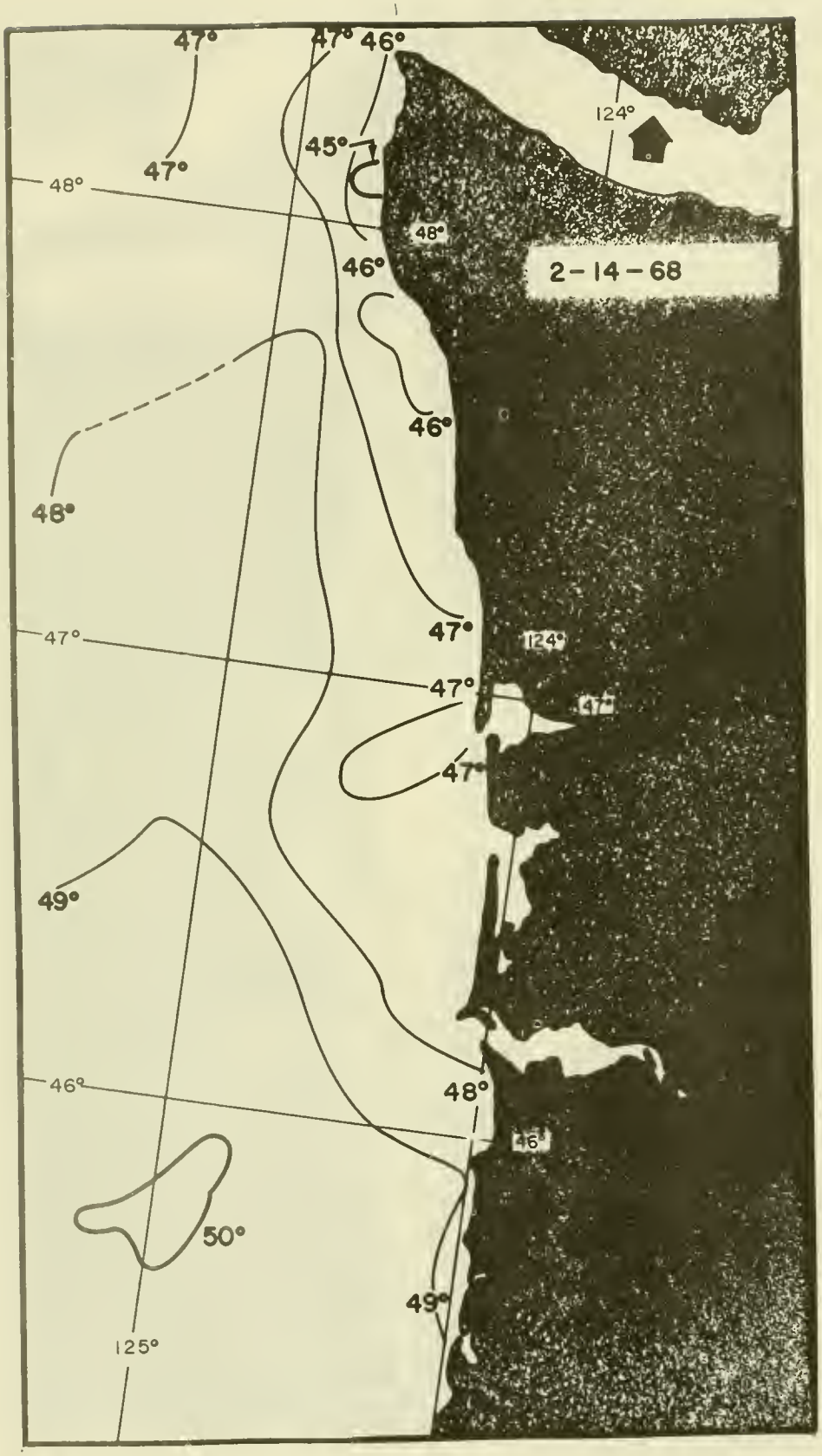
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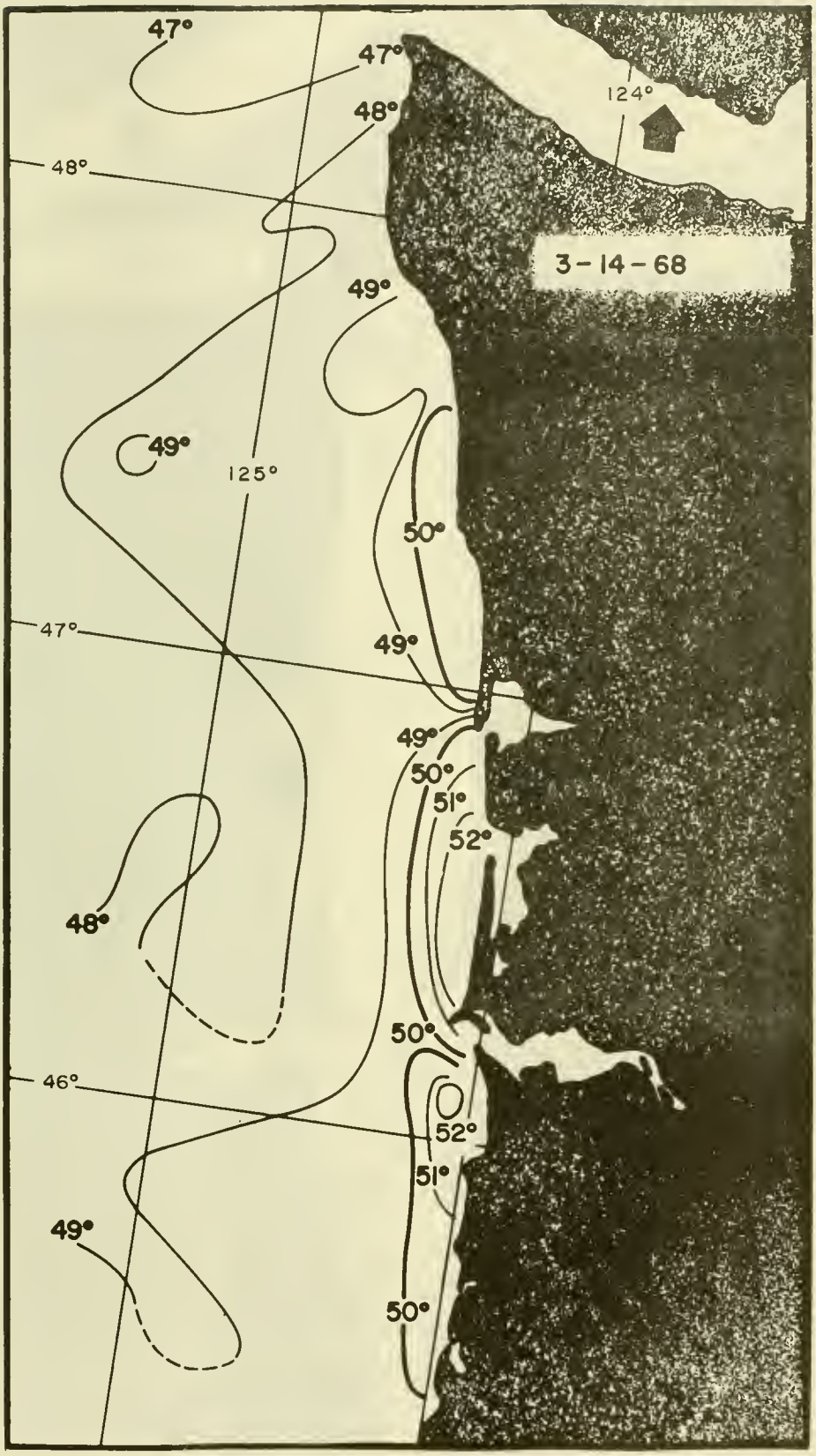
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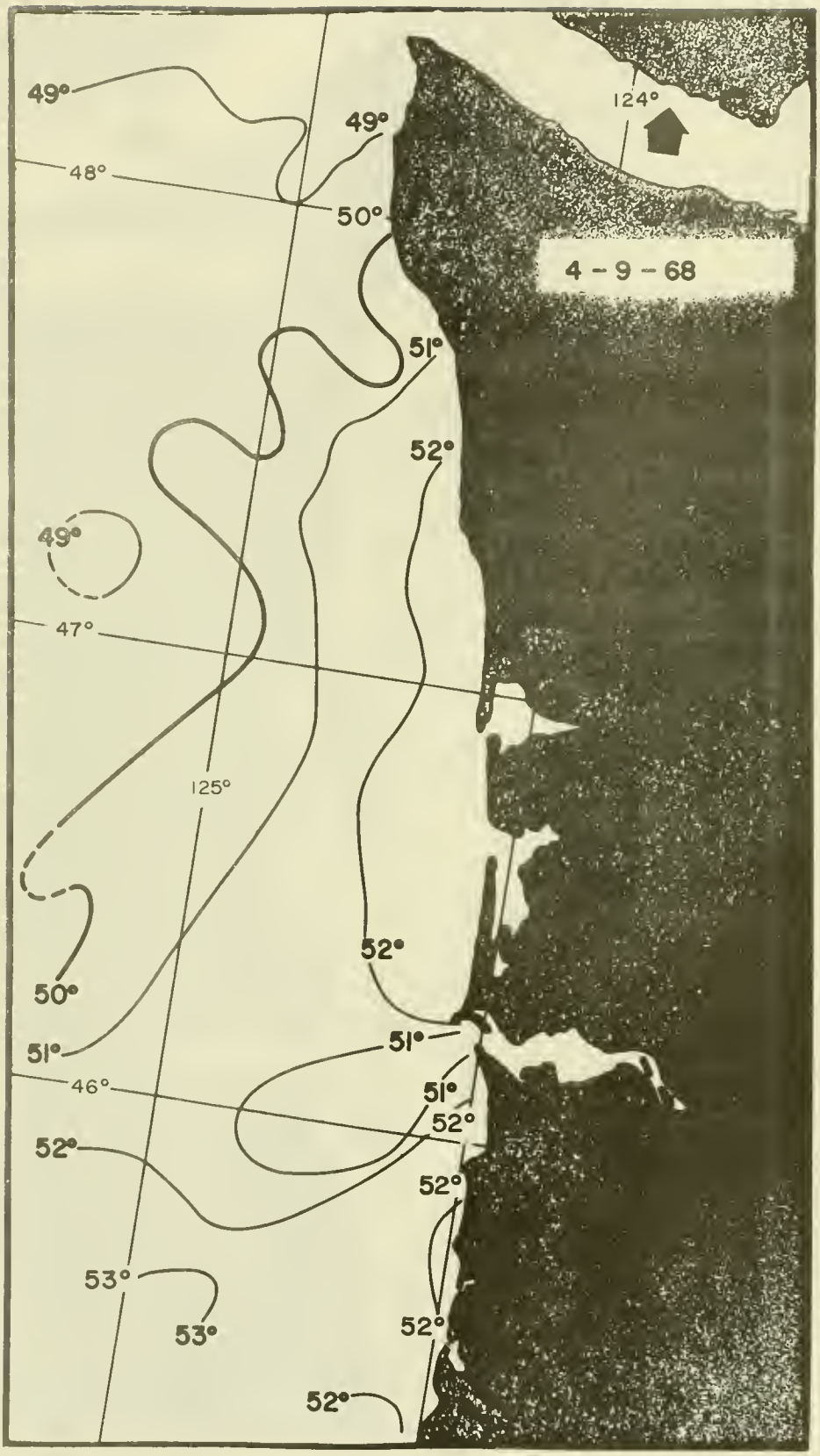
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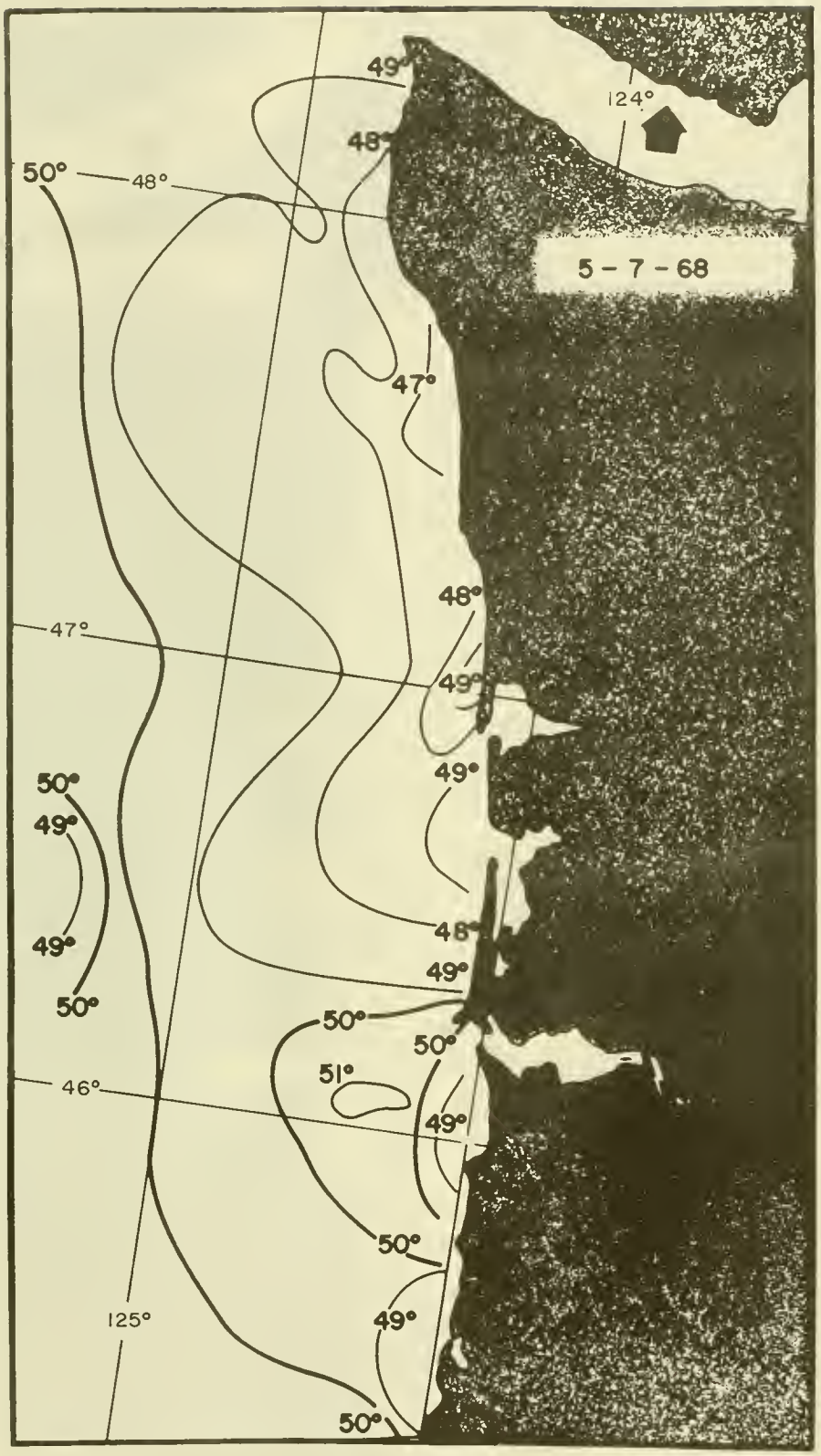
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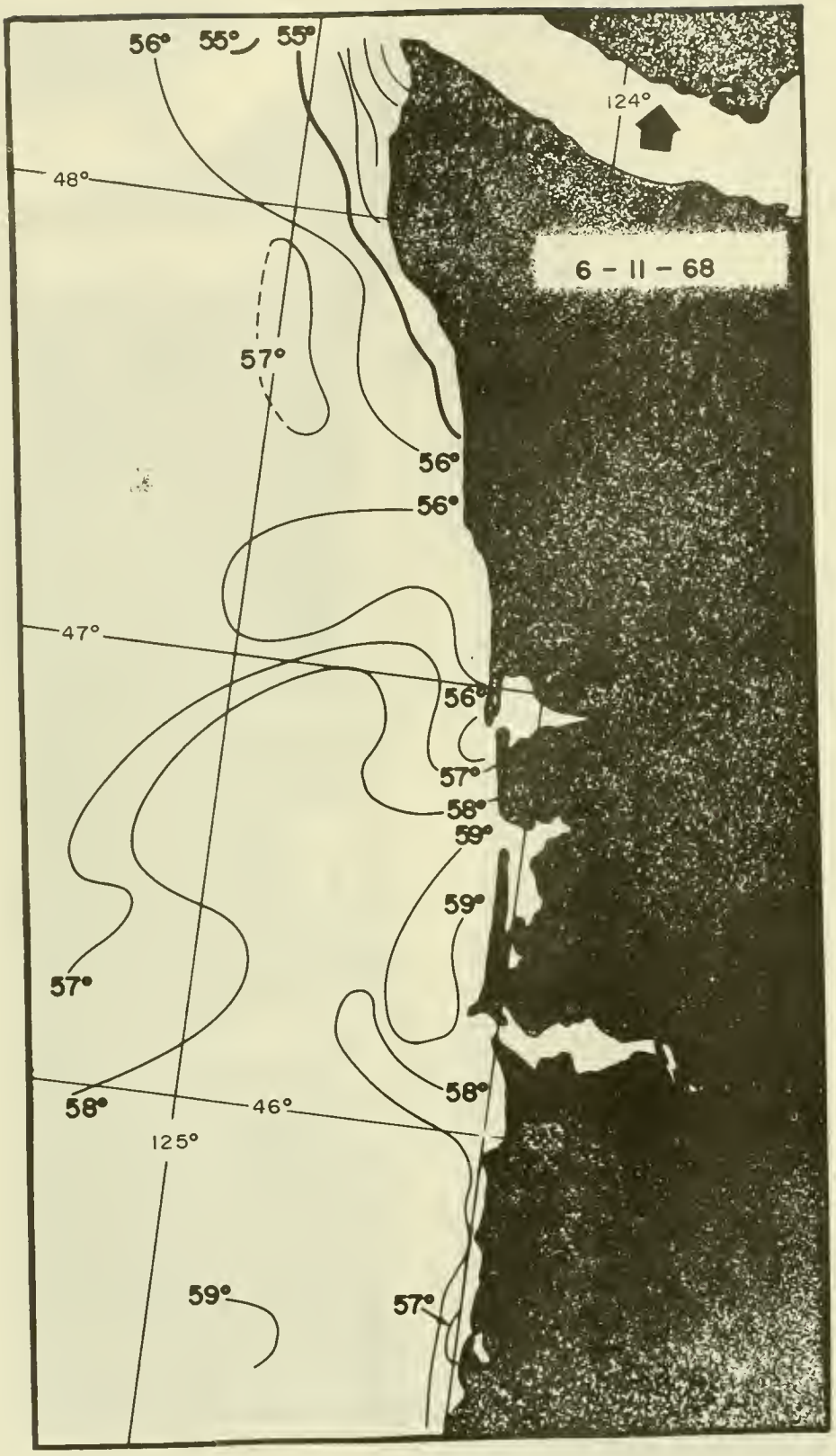
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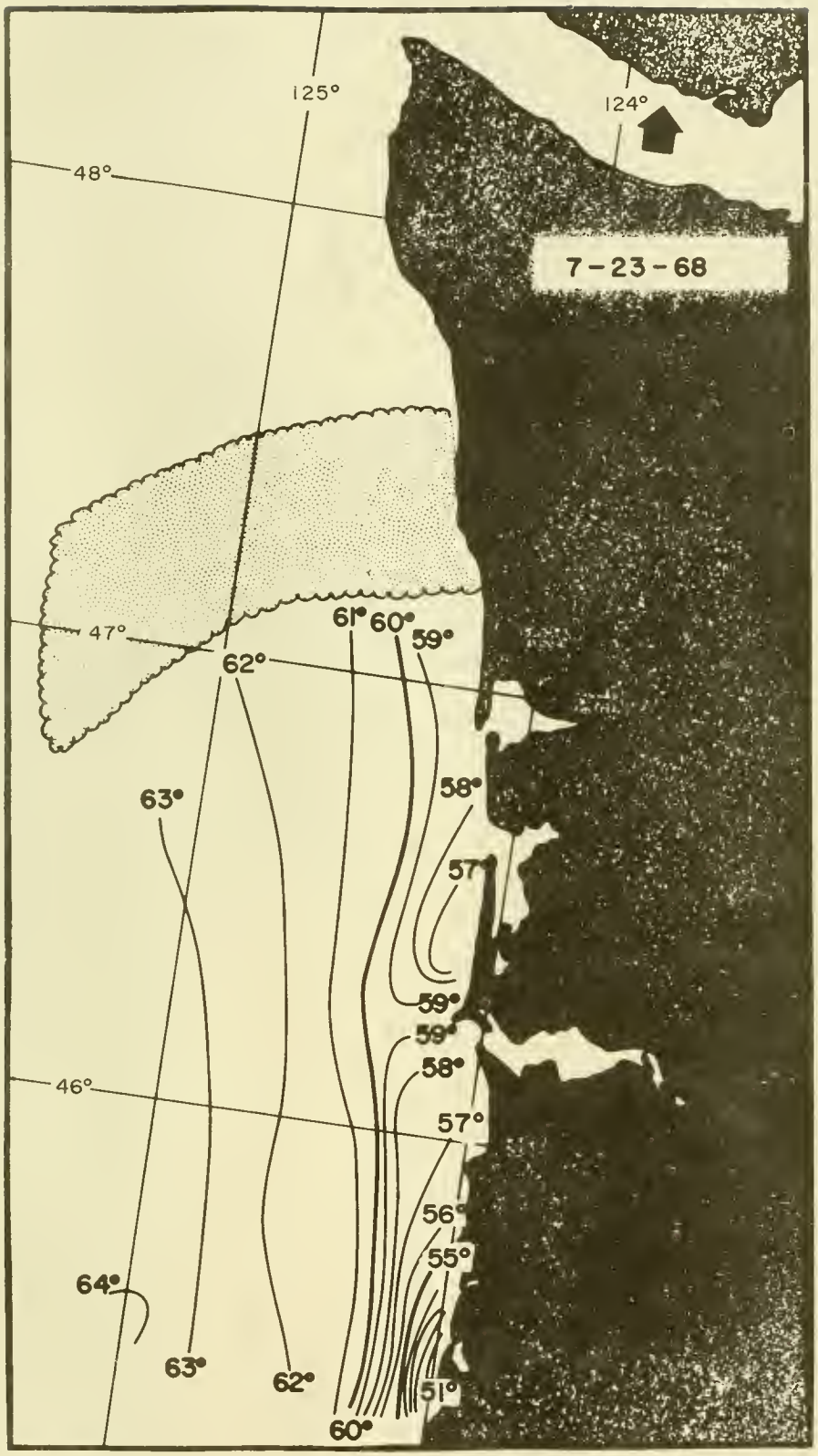




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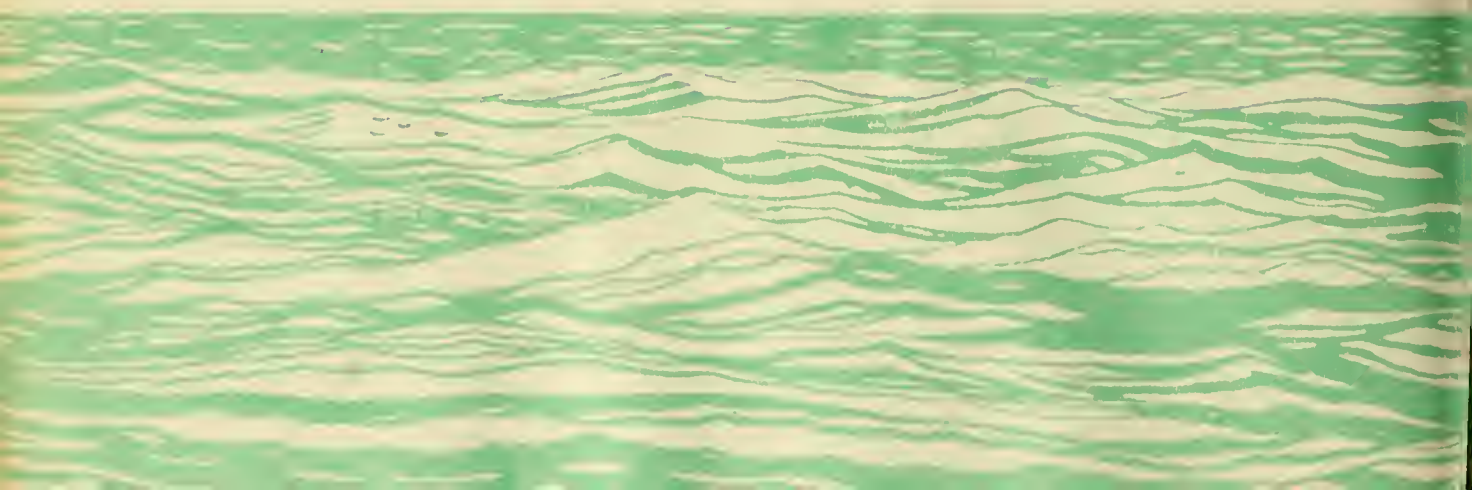
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